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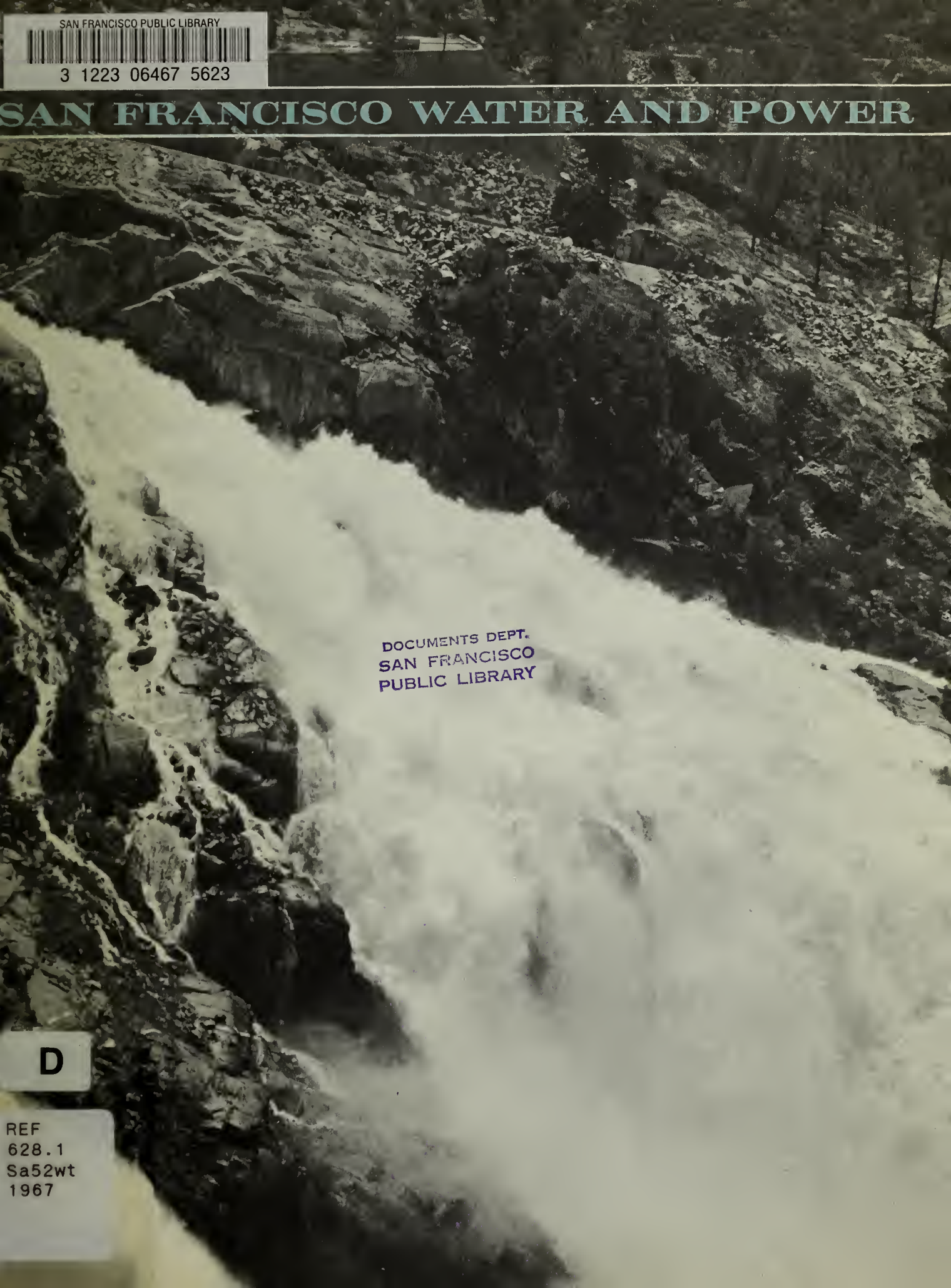

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Introduction

The City and County of San Francisco owns and operates a water and power system in which its residents take great pride. Its conception and achievement is an engineering feat of great magnitude, a contribution not only to the welfare of the people, but also to the development of San Francisco and the general metropolitan area. Modern urbanization demands ever increasing supplies of clean, inexpensive water. There are not many cities in the United States that have a water supply so dependable, of such excellent quality, and adequate to all foreseeable needs well into the next century.

In the first decade of the twentieth century, San Francisco was one of only two major cities in the United States relying on a private company for its water supply. The inadequacy of this supply for the future was evident at that time and the people, empowered by the city charter of 1900, set out to develop and build their Hetch Hetchy Project. This system taps the water of the Tuolumne River, flowing out of the snow-capped Sierra Mountains over 149 miles east of the city.

After securing rights-of-way and water rights, the City's engineers began construction of facilities which would bring the water to San Francisco. There were problems of financing such a vast project by a municipality as small as San Francisco was at that time. But, by completing revenue-producing facilities first and by carefully extending initial construction over a period of twenty years, City Engineer Michael M. O'Shaughnessy was able to keep the work barely within financing capabilities. After an expenditure of 100 million dollars, the first water flowed into San Francisco in 1934.

In 1930 the City insured control of its own water supply by purchasing all the water rights and operative properties owned by the Spring Valley Water Company, and has developed all these local resources to the fullest extent. Since acquisition, these facilities have been operated by the San Francisco Water Department with most satisfactory results.

Through long-range planning and construction, San Francisco has continued the development of its overall water and power resources. The municipal system, including impounding and storage reservoirs, aqueducts, water distribution facilities, hydroelectric power plants, and electric transmission facilities, extends almost completely across the state of California, from the summit of the Sierra Nevada to the San Francisco Bay Area. Up to the present time, nearly 500 million dollars has been spent or committed on these facilities, and plans contemplate additional future expenditures for improvements and expansion.

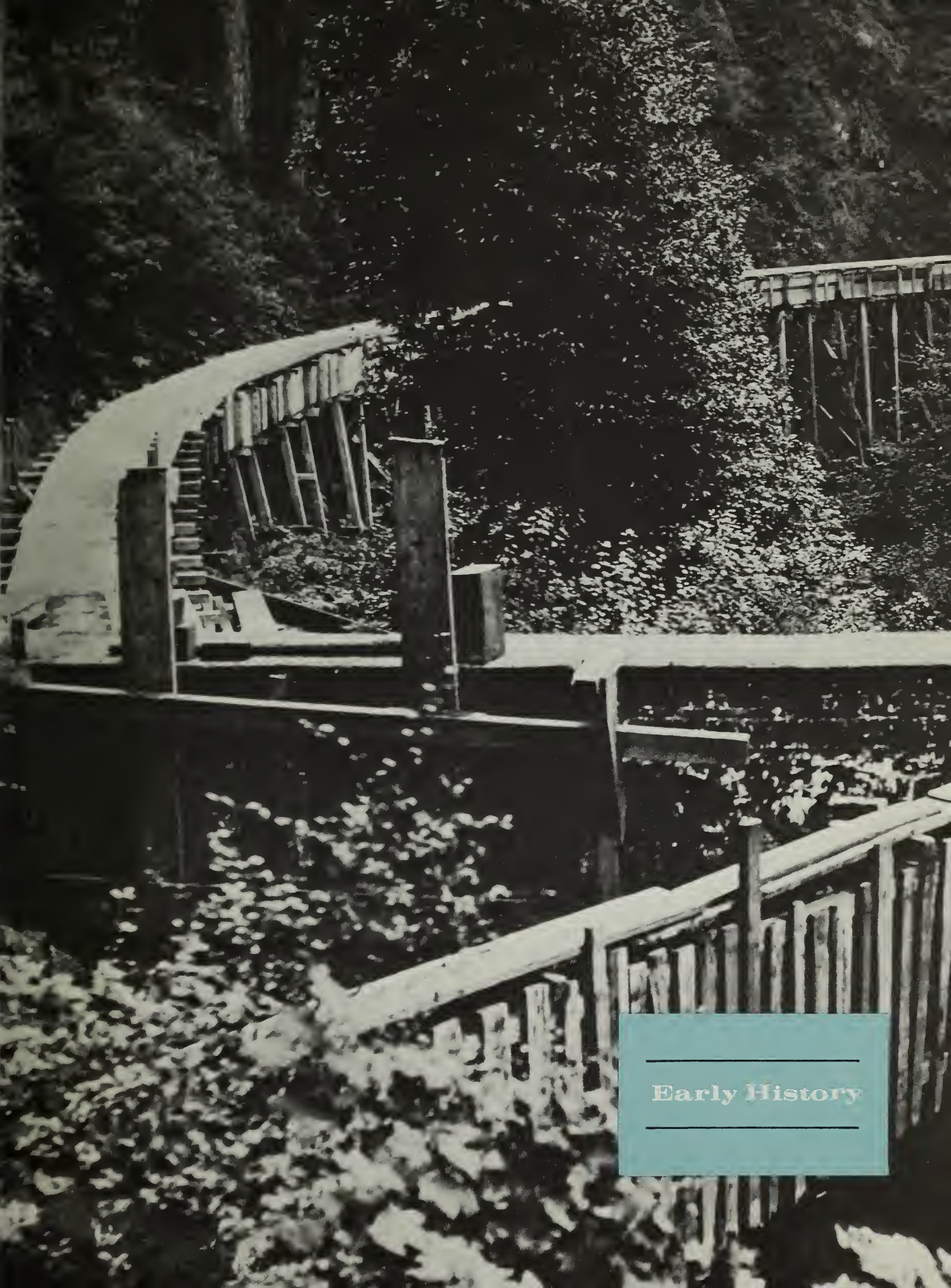
An impressive average of more than 225 million gallons of water daily, with a system peak of more than 300 million gallons per day, is delivered to two million consumers directly through 156,000 individual service connections and through the distribution facilities of more than 40 other municipal and water distributing agencies. This water is supplied for residential, commercial, and industrial use in a 500-square-mile service area comprising San Francisco as well as neighboring communities in most of San Mateo County and in parts of Santa Clara and Alameda Counties. In fact, more than half of the consumption is in suburban areas outside of San Francisco. Water rates in the City are approximately seventeen percent below those in effect in 1930, when the City acquired the Spring Valley system. Furthermore, there are no tax subsidies required to keep these rates attractive, as is necessary in other areas.

Two billion kilowatt-hours of electric energy are generated annually in the City's three hydroelectric plants of 290,000 kilowatts system capacity. This power is used for municipal functions, such as streetcars and trolley buses, street lighting, and traffic signal systems. It also is sold to a pair of large irrigation districts in the agricultural areas of California, and to several large industrial customers.

In connection with its water and power operations, San Francisco owns about 60,000 acres of land in seven counties: Tuolumne, Stanislaus, San Joaquin, Alameda, Santa Clara, San Mateo, and San Francisco. About half of this land is being used by others, under lease or permit, for a large variety of operations such as golf courses, parks and picnic areas, a gravel pit, farming and ranching, a restaurant, and other types of commercial enterprises.

This water and power system is a self-supporting municipal utility placing no burden on the taxpayers. Operating and maintenance costs are paid from current income. Improvements and expansion programs are financed from revenue or from bonds which are redeemed through subsequent revenue. Income from sales of water, power, and from miscellaneous sources exceeds 30 million dollars annually. Water is furnished to San Francisco City and County departments without charge, and electricity for municipal purposes is supplied at cost. For the taxpayers, these factors amount to a saving of over two million dollars per year.

The water and power properties are under control of the San Francisco Public Utilities Commission, whose policies are administered under the direction of the General Manager of Public Utilities. Water production and delivery from the High Sierra to the Bay Area, as well as electric power generation, transmission, and sales, are all managed by the Hetch Hetchy Department. Water storage, distribution, and sales in the Bay Area are managed by the San Francisco Water Department.



Early History

San Francisco

The San Francisco Bay Region is classified as being semi-arid. The City itself sits at the end of a fifty-mile long peninsula, with salt water on three sides. Therefore, the local water supply is quite limited. The struggle for it began in 1776, when Franciscan missionaries selected a small stream as the site of their Mission St. Francis de Assisi (now known as Mission Dolores and not far from the center of town). The gold rush of 1849 rapidly transformed the sleepy little pueblo of Yerba Buena into the booming town of San Francisco.

One of the major problems was to find an adequate supply of water. Some residents obtained a supply from their own wells or from local springs, while others bought water from peddlers, who ferried the precious liquid in barges from Marin County, across the Golden Gate. There were actually "water routes," similar to present-day milk routes, where water was delivered from barrels. It is reported that during one period of scarcity water sold for one dollar in gold per bucket.

In 1857 the San Francisco Water Works was formed. Tapping Lobos Creek, which ran through the present Richmond District in western San Francisco, the company was able to supply two million gallons of water a day through five miles of flume and tunnel along the Golden Gate shoreline to a pumping plant at Black Point, near the present Aquatic Park. From this point the water was pumped to storage places on Russian Hill—the Lombard and Francisco reservoirs, which are still in use. Small amounts of water were developed elsewhere locally, but realizing the limitations of these sources, the Spring Valley Water Works, which had been organized in 1860, pressed south into San Mateo County and began the development of what is now the Peninsula system. San Francisco Water Works was absorbed by Spring Valley in 1865.

First complete unit of the Peninsula system was a reservoir constructed on Pilarcitos Creek, about ten miles south of the city. From here water was carried in pipes and redwood flume to Laguna Honda Reservoir on Seventh Avenue. First delivery from this source was in July 1862. Shortly after that, the water company acquired rights at spring-fed Lake Merced near the ocean and continued its development of the Peninsula sources by adding the San Andreas Reservoir in 1870. Upper Crystal Springs Dam was completed in 1878, and Lower Crystal Springs Dam in 1890 was the final unit in the development of reservoir sites on the peninsula area to the south of San Francisco.

As early as 1871 the city's engineers foresaw that water resources of the region would be inadequate for future population. Within the Coast Range Mountains, the regions to the south and east of San Francisco Bay had no surplus water; streams to the north were inadequate and virtually inaccessible. A special

study committee in 1875 had recommended the purchase of Calaveras Valley in southern Alameda County as a future water supply, but Spring Valley officials wanted no rival and themselves bought this property before the City could act. Recurrent dry seasons and the inadequacy of water supply demonstrated by numerous tragic fires kept the problem always prominent in City politics. Controversies were continually arising between the water company and city officials as to rates and the adequacy of service.

Meanwhile, the Spring Valley company acquired extensive water rights, in addition to Calaveras Valley, in Alameda and Santa Clara Counties. In 1887 a pipeline was laid to carry water from Alameda Creek watershed across and under the southern end of the bay to connect with the Peninsula system. Further developments in the Alameda sources included sinking of wells in the gravel beds of the Pleasanton area, construction of tiny Sunol Dam with a series of underground filtration galleries, and eventually the completion of Calaveras Dam in 1925.

Sierra Nevada Mountains

Following numerous investigations and reports by engineers and committees on behalf of the City, far-sighted citizens began to realize that the only satisfactory solution to the problem was municipal ownership. And it was determined that the City must look beyond the Coast Range for its future water supply. This meant the Sierra Nevada Mountains running along the eastern edge of the state. From San Francisco this was a distance of fifty miles across the Coast Range, another fifty miles across the low-lying San Joaquin Valley, and then fifty more miles across the Sierra foothills to the mountains proper—a total of at least 149 miles! This was a tremendous challenge to be faced by a city with less than 350,000 population, supported by the few scattered communities around the bay at that time, but it was a situation that had to be met, if the Bay Region were to continue to grow.

In 1901, during the administration of Mayor James Phelan, the city engineer made exhaustive surveys and reported on fourteen possible water sources. The investigation established the superiority of the Tuolumne River for the following reasons:

Purity of the Water
Largest Amount of Water Available
Largest and Finest Reservoir Site
Freedom from Conflicting Legal Claims
Electric Power Possibilities

The Tuolumne River, with its source in a perpetual glacier on 13,000-foot Mount Lyell, drains 652 square miles of watershed in rugged granite mountains sloping west from the crest of the Sierra Nevada. Of this watershed area, 92% is above 6,000 feet elevation. In its picturesque descent the river flows through the northern reaches of Yosemite National Park and through the Stanislaus National Forest. It emerges

from the foothills near La Grange, flows out into the valley and empties into the northbound San Joaquin River ten miles west of Modesto.

Following the decision in 1901 to develop the Tuolumne River watershed, steps were immediately taken toward acquisition of the necessary rights. Publicity was avoided as far as possible in order to prevent private parties and corporations, more mobile than the City, from forestalling the City's action. All applications for water and reservoir rights were made in the name of Mayor Phelan in his capacity as a private citizen. Phelan in 1903 assigned his interests to the City and County of San Francisco, and the battle, started in 1901, hit full stride and continued for the next ten years.

Raker Act

The mountain development was named Hetch Hetchy Project, taking the name of a small mountain valley north of Yosemite. This flat valley, six or seven miles long and with steep granite walls, was to be the main storage reservoir. From prehistoric times the local Indians had referred to the area as "Hatchatchie," a Central Miwok Indian designation for a plant or grass, bearing edible seeds, which grew profusely in the area of Hetch Hetchy Valley.

The City's plan to build a reservoir within the boundaries of a national park precipitated a lengthy battle. Although conservation groups were the most vociferous of the opposition, this opposition was instigated primarily by corporate interests hostile to municipal ownership of public utilities or financially interested in rival water-supply projects. Irrigation districts, users of Tuolumne River waters for many years, were fearful at first lest their supplies would be diminished. The application filed in 1901 for permission to construct the necessary dams and conduits and to use the reservoir sites, was denied by Secretary of the Interior E. A. Hitchcock. The City continued its efforts to secure the necessary permission, being interrupted briefly—but not deterred—by the earthquake and fire of 1906.

Secretary of the Interior James R. Garfield subsequently reopened the proceedings in San Francisco and in 1908 gave his approval. This approval, known as the "Garfield Permit," granted the City rights-of-way for dams, reservoirs, and aqueduct lines and was revocable under certain conditions. Now the people of San Francisco declared themselves almost unanimously in favor of the project by voting a $600,000 bond issue in 1908 for the purchase of privately-owned lands and water rights and, in 1910, by voting a bond issue of $45,000,000 to finance the construction.

However, in that same year a new Secretary of the Interior, Richard A. Ballinger, cited the City to show cause why part of the permit—that applying to Hetch Hetchy Valley—should not be revoked. This fact, combined with the possibility that San Francisco would be subject to the whims of successive administrations

Survey Party from San Francisco, 1912 (Photo: Ted Wurm)

in Washington, led the City authorities to ask Congress for an outright grant of the desired privileges.

There followed an extended and heated battle in Congress, with the private water company and its spokesmen making inflammatory claims and charges and the City's plans being firmly backed by an Advisory Board of Army Engineers appointed by the President. Finally, the Hetch Hetchy Grant, known as the Raker Act, was passed by both Houses of Congress and signed into law on December 19, 1913, by President Wilson, who made the following written comment about the Hetch Hetchy plan:

> ". . . it seems to serve the pressing public needs of the region concerned better than they could be served in any other way, and yet did not impair the usefulness or materially detract from the beauty of the public domain."

The Raker Act, taking its name from California Congressman John Edward Raker, granted to San Francisco rights-of-way and the use of public lands in the areas concerned for the purpose of constructing, operating, and maintaining reservoirs, dams, conduits, and other structures necessary or incidental to the development and use of water and power.

That the Raker Act did not constitute a free gift to the City, as has been claimed, is demonstrated by a consideration of the many conditions and obligations imposed upon San Francisco by the Act. Among numerous requirements, the Raker Act stipulated that the City had to do the following things:

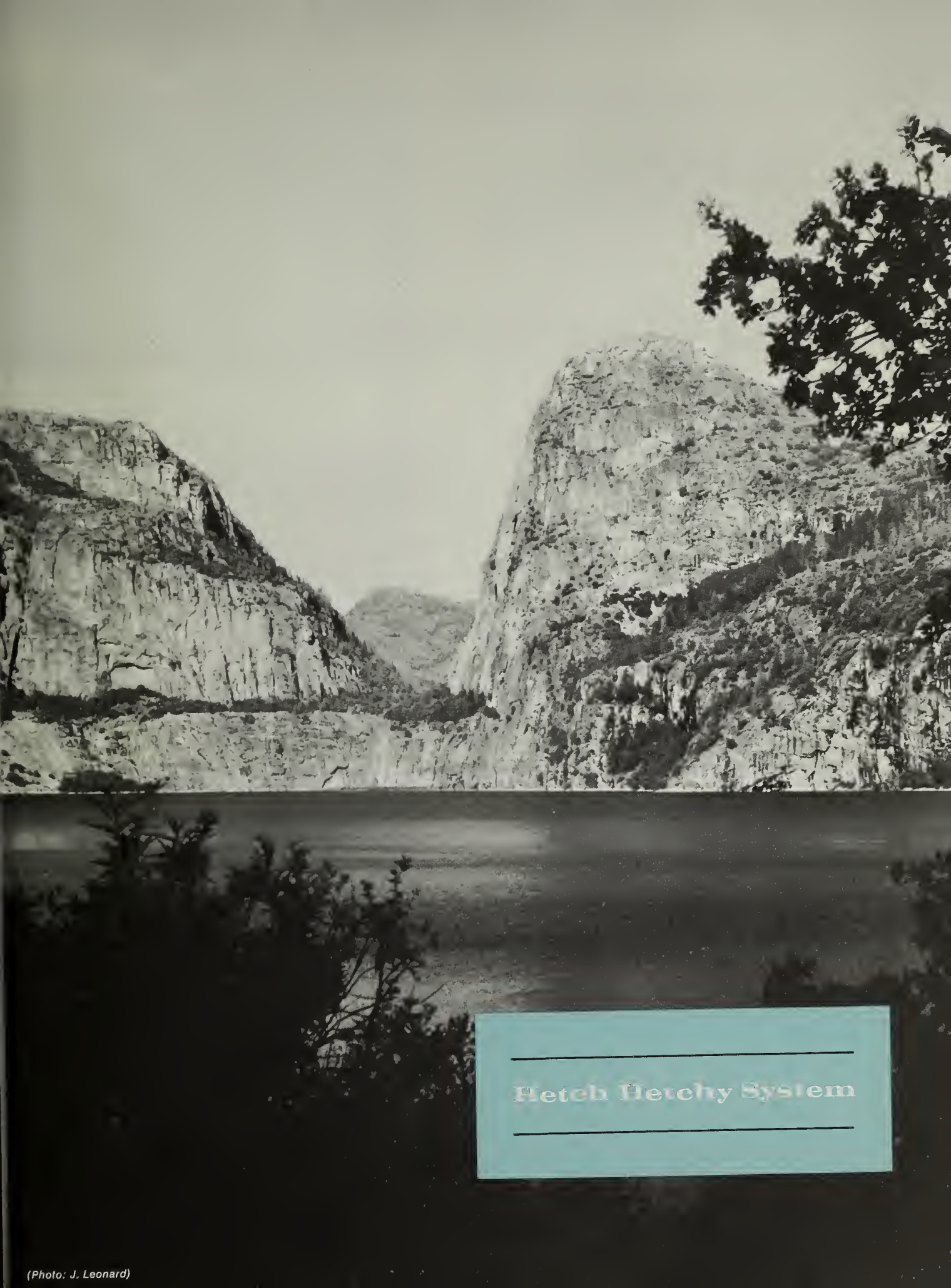
1) Construct miles of scenic roads and trails in Yosemite National Park and donate them to the United States;
2) Enforce sanitary regulations within the watershed area;
3) Recognize the prior rights of Turlock and Modesto Irrigation Districts to receive water they can beneficially use—up to specified amounts of the natural daily flow—for direct use and storage;
4) Get the work of dam building at Hetch Hetchy completed as rapidly as possible;
5) Develop electric power for municipal and commercial use;
6) Not divert beyond the limits of the San Joaquin Valley any more of the waters than would be required for its own domestic or municipal purposes (this excluded irrigation use);
7) Not sell or give Hetch Hetchy water or power to a private person or corporation for resale;
8) Pay an annual rental starting at $15,000 and rising to $30,000 after twenty years.

The irrigation districts involved ended up supporting the Raker Act, once they were assured that their rights were protected and they would actually benefit from electric power surpluses. And the opposition from Spring Valley Water Company subsided at the inclusion of a special clause in the Act that provided for the utilization of all of the water from sources near San Francisco, before water from the Tuolumne could be diverted. This protected that company in its investment in all properties and rights up to the full amount of their capacity.

The Raker Act is an excellent demonstration of the "conservation for use" policy, whereby a great advantage was gained for millions of people and very slight damage done. It expressly disclaims any intent to interfere with the laws of the State of California relating to the control or appropriation of water. The Act was ratified by the City in the Spring of 1914 and the Hetch Hetchy construction program was immediately initiated.

The City of San Francisco was still engaged in one of history's greatest construction jobs—rebuilding the city destroyed by earthquake and fire in 1906—when the work on Hetch Hetchy began in earnest eight years later. But this was a city loaded with engineering talent of the highest order—city engineers and private consultants ready for any challenge that tested their imaginations. Some of the finest engineering brains of the period "signed up" with San Francisco because they liked the concept and they respected "The Chief"—City Engineer Michael M. O'Shaughnessy. The inducement which drew this fine man to the job was the guarantee of a free hand and plenty of support by far-seeing Mayor Rolph.

There were numerous obstacles besides the mountains and other engineering problems—there was a 75 percent rise in prices from 1913 to the end of World War I, for instance, and there were attempts at political interference and foot-dragging on appropriations—but San Francisco had earned the title, "The City That Knows How," and Hetch Hetchy was built.



(Photo: J. Leonard)

General Description

The mountain water supply system includes three impounding reservoirs: Hetch Hetchy on the Tuolumne River, Lake Lloyd on Cherry River, and Lake Eleanor on Eleanor Creek. The latter two streams are tributaries of the Tuolumne. Each year, the runoff from rainfall and melting snow is collected behind the dams. Water stored in Lakes Lloyd and Eleanor is utilized to generate power at Dion R. Holm Powerhouse and to meet downstream irrigation priorities. Storage in Hetch Hetchy Reservoir is drawn upon mainly for San Francisco's domestic and suburban water supply, and in the course of its journey it generates electric power at Robert C. Kirkwood and Moccasin powerhouses.

Water released from Hetch Hetchy flows through a spectacular series of tunnels, pipelines, inverted siphons, and powerhouses. It is led down the Sierra slopes, through the foothills, across the great San Joaquin Valley, through the Coast Range Mountains, under and around San Francisco Bay to finally reach Crystal Springs, a terminal reservoir on the Peninsula. The water flows 149 miles through this marvelous system entirely by gravity! The far-seeing builders made a water supply route entirely free from the great and unending expense of pumping; they built a system in which the pure mountain water is completely enclosed and protected — except at regulating reservoirs — for the entire distance. This source supplies over three-quarters of the total consumption in the City's water service area.

In passing through this impressive system the water is used to generate power on its downhill journey. When flowing water drops in elevation and passes through power plants, it generates electric energy. Under the Raker Act, San Francisco is required to develop these power resources, and the revenue from this power is an important factor in financing the project.

Preliminary Work

Plans for the Hetch Hetchy Project had been drawn up in turn by City Engineer C. E. Grunsky and his successor, Marsden Manson. The latter had devoted twelve years almost exclusively to the project, even when out of office. O'Shaughnessy came to the City in 1912, the year Rolph was elected mayor. The people had shown their approval of the water project with passage of the necessary bond issues in 1908 and 1910.

San Francisco now engaged the services of John R. Freeman, an internationally-known consulting engineer, to prepare a preliminary design of the entire project, with estimates in some detail, for developing ultimately 400 million gallons of water per day and transporting it to the Bay Area south and east of the City. After exhaustive studies, the "Freeman Plan" for Hetch Hetchy development was published in 1912

Diversion tunnel carried river around construction site

Preliminary work on floor of Hetch Hetchy Valley (Photo Ted Wurm)

Building the Hetch Hetchy Railroad into the mountains.

and was in large part responsible for the favorable findings of the Board of Army Engineers in Washington, which findings resulted in the Raker Act.

As men from his office went into the mountains on foot and by horseback for the final surveys, City Engineer O'Shaughnessy and his assistants made a number of important changes in the Freeman Plan. These changes added to the capacity of the project, worked for ease of supply and construction, and lessened the expense to the taxpayers.

Since Spring Valley Water Company sources could supply the water requirements for at least ten years, immediate delivery of Hetch Hetchy water was not necessary. On the other hand, electric power development was of vital importance throughout California at the time. Thus, it was to the advantage of San Francisco to begin as soon as possible to generate the power resulting from water development, so that the revenue from power sales could be used to pay interest and redemption charges on bonds, thereby reducing the burden to be carried by the taxpayers in regard to the water project.

It was decided first to build the dam at Hetch Hetchy to about three-quarters of its ultimate height and thus develop about 60% of the ultimate reservoir capacity. The aqueduct to carry the water westward would be completed as far as Moccasin Creek and a powerhouse put in operation at that place as soon as possible. Another section of the aqueduct, 23 miles in length, would be built from Alameda Creek across the bay to Crystal Springs Reservoir. This would be ready to carry additional water of the Spring Valley Company, when developed, giving income to the City, and could later carry Hetch Hetchy water as the system was built westward. The remaining parts of the aqueduct were to follow in time to have the mountain water ready for delivery when Spring Valley sources would no longer be adequate, but no sooner than necessary, in order to minimize the financial burden on San Francisco.

The magnitude of the undertaking was complicated by the inaccessibility of the region. In a country difficult even for mountain climbers, with only a few spots in which horses could be cared for, it was proposed to build dams and electric plants, transport all manner of machinery and equipment, and supply accommodations for thousands of workmen. But no area could be considered inaccessible when electrically-driven drills had been invented to bore into granite, and dynamite was available as the moving force.

Before proceeding with construction of the essential parts of the system, it was necessary to get into the mountains with packers and guides, often using chartered stagecoaches and freight wagons out of Groveland. The latter was a small mountain town left over from the gold rush and sitting quietly astride the Big Oak Flat road into Yosemite. Groveland was

revitalized with the coming of the City of San Francisco into the area, and for a decade it boomed as the City's headquarters for the mountain project. Into this quiet country village were suddenly thrust office and hospital buildings, homes for officials and their families, along with the shops and operating headquarters of a full-size railroad, bringing the first trains that some of the Groveland children had ever seen. City men and equipment helped with extensive road improvements in the district; they improved the water supply and initiated a system of sewers; they resurveyed Groveland and nearby Big Oak Flat to correct inaccurate surveys made in gold rush times of the 1850's.

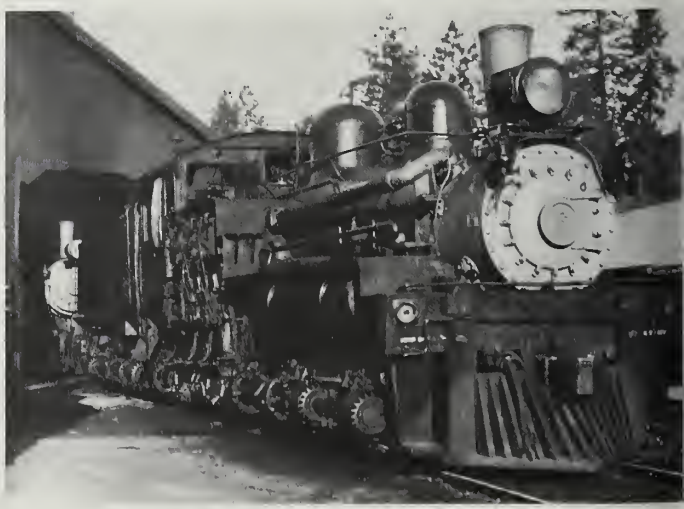
Hetch Hetchy Railroad

The Hetch Hetchy Railroad was a major piece of construction and was essential to the completion of the project within cost estimates. From a connection with the Sierra Railway at Hetch Hetchy Junction, 26 miles east of Oakdale, it extended for 68 miles into the heart of the Sierra, right to the rim of Hetch Hetchy Valley at the site of the proposed dam. At a cost of approximately $2,000,000, the railroad was built to serve the main dam construction, as well as all the working points on the thirty miles of main aqueduct east of the Sierra Railway, and the power development on Moccasin Creek. Some of these points were served directly by the trains, others through spur tracks, tramways, or short motor truck hauls. Maximum grade was four percent—the railroad climbed from 600 feet above sea level to an elevation of over 5,000 feet at Poopenaut Pass, six miles from Damsite station. For the many sharp curves, specially-designed steam locomotives had to be used and they worked out most successfully.

Great savings were realized by building the Hetch Hetchy Railroad. The actual cost of transporting the thousands of tons of cement alone was only one tenth of what the cost would have been by motor truck in that rugged country—and trucks couldn't operate at all when winter snows blocked the roads! Although main use of the railroad was discontinued in the mid-20's with completion of the dam and aqueduct, the line was used for twenty years more as a supply and maintenance route in wintertime, when roads in the higher elevations were snowbound for months.

Tracks were finally taken up in 1949 and parts of the old railroad right of way were used for a new road into Hetch Hetchy and in improvements to make the Big Oak Flat Road an all-year access to Yosemite Valley. It is interesting to note that, of six steam locomotives owned by the Hetch Hetchy Railroad and scattered to the four winds in the 1920's, four have been preserved in transportation museums. One is at Yosemite National Park; two are in Traveltown, Los Angeles, bearing the names of subsequent owners, and the fourth is in the state of Oregon.

Hetch Hetchy Railroad, vital link in winter season



Engine #6 has been preserved for display at Yosemite National Park (Photo: Ernie Beck)

1921 Grand Jury makes inspection trip by Hetch Hetchy train

The City had acquired valuable timber lands in the vicinity of the construction sites. A large sawmill was built and operated by city forces at Canyon Ranch, near Hetch Hetchy. In a few years it was moved to Hog Ranch—later named Mather, the site of today's San Francisco recreation camp, which uses many of the structures from construction days. Finished lumber was shipped from this sawmill to the various camps along the railroad, to be used for concrete forms, camp buildings, flumes, tunnel timbering, and all sorts of construction. Lumber from privately-owned sawmills along the line was carried out of the mountains over the Hetch Hetchy Railroad—income from this and other traffic served to lessen the cost of operation.

Lake Eleanor

To provide power for construction requirements, a small hydro-electric plant was built at a place named Early Intake, on the Tuolumne River about twelve miles downstream from Hetch Hetchy. According to old timers, the name Early Intake was informally applied to the first selected site for the entrance of the mountain tunnel which would carry Hetch Hetchy water westward, and the informal designation became the name of the place. To get water to turn the wheels at this first powerhouse, engineers forced a switchback road from Hetch Hetchy back into the mountains and built a multiple-arch concrete dam to store 28,000 acre feet of water at Lake Eleanor.

This first dam of the Hetch Hetchy system, completed in 1918, is 70 feet high and 1260 feet long. Water released from Eleanor, combined with the natural flow of Cherry River, was diverted by a small dam into the Lower Cherry Aqueduct. This was a three-mile system of tunnels and concrete-lined canal, flumes, and pipes, with a capacity of 200 cubic feet per second.

Power System

This small aqueduct terminated on the hillside above Early Intake Powerhouse, turning its flow into a penstock which led to the turbines. There were three 1500-horsepower Pelton turbines operating under a head of 345 feet (vertical distance of the fall of water). Each turbine was direct connected to a 2300-volt generator with a rating of, eventually, 1000 kilowatts. In the form of electricity, 4000 horsepower was transmitted to the many construction sites throughout the "Mountain Division" at 22,000 volts. Wooden pole transmission lines extended eleven miles eastward to Hetch Hetchy damsite and 22 miles westerly to the site of Moccasin Powerhouse.

After early construction was completed, this pioneer powerhouse continued in operation until 1960, adding its production of electricity to that of Moccasin. Since 1960, water stored at Lake Eleanor is diverted through a mile-long tunnel into the Lake Lloyd Reservoir on the Cherry. Future plans contemplate the enlarging of Lake Eleanor.

Lake Eleanor Dam during construction (Photo: Bud Meyer)

Aerial view of Lake Eleanor and the dam

Engineers locate diversion dam in Hetch Hetchy Valley

Clearing for dam foundation, 135 feet below streambed

Planning For A Century

From the early days of planning and throughout the period of preliminary work, the Hetch Hetchy Project was set up with a hundred years of service as a minimum result sought for. Taken into consideration were the water needs of the entire San Francisco Bay Region until well into the 21st Century. Originally, the City had been looking for an additional source of only sixty million gallons a day. However, on the advice of the Army Board of Engineers in 1913, it found itself assuming the leadership for all the people around the Bay—a total population of about one million at the time of the Raker Act.

Full development of the Tuolumne River would give San Francisco over 400 million gallons daily; this, with local supplies, would provide water for four million population. Such a population was predicted for the area for soon after the year 2000. Thus, San Francisco found itself chosen to undertake the full development of this amount of water. The tremendous surge of California population growth could not possibly have been predicted by anyone 50 or 60 years ago—it far exceeds all estimates for the area around San Francisco. Fortunately, in the early twenties, the cities on the eastern side of the bay, across from the City and County of San Francisco, pulled out of Hetch Hetchy and found and developed their own supply from the Mokelumne River.

This change enabled San Francisco, without any undue strain, to meet the constantly increasing requests for water from the mushrooming surburban areas and industrial complexes stretching for nearly fifty miles southward from the city limits. The plan for one hundred years was basically sound and fortunately able to take care of tremendous increases in water requirements. The Hetch Hetchy Project was planned and built in such a way that none of the work has had to be done over. Planned additions can be made to various parts as needs arise. An increase in capacity on various parts of the aqueduct can be made without changing the basic design—this was incorporated into the original planning and the preliminary work, then built right into the project itself.

The Hetch Hetchy system was built as economically as possible, but where added expense was thought necessary to eliminate future outlays and endless maintenance, the work was done. In the years that followed, it was demonstrated again and again that the builders acted wisely. The initial development of Hetch Hetchy—up to the first flowing of water into the City in 1934—cost approximately $100,000,000. This expense was met entirely by a city, without state or federal assistance, and it was set up to meet foreseeable needs for 100 years. San Francisco bought herself a bargain. Let's see what it consists of.

Concrete pouring at O'Shaughnessy Dam, August 1921

O'Shaughnessy Dam and Hetch Hetchy Reservoir

In 1915 preliminary work began in preparation for construction at the lower end of Hetch Hetchy Valley of the dam which would help form the major impounding reservoir in the mountain system. This reservoir collects and stores the runoff from 459 square miles of rugged granite mountains. Built of concrete, the big dam is of the arched gravity type with five vertical contraction joints sealed by strips of sheet copper; at each contraction joint there is an inspection well with ladderway. Construction of the original dam took nearly four years and nationwide interest was created by the engineering details. Among the thousands who came to view the work in progress were large groups of campers from Yosemite Valley.

For the Yosemite tourists, large open buses left the valley early in the morning for a three-hour mountain ride to Mather station on the Hetch Hetchy Railroad. From that point they were carried in special gasoline-propelled railroad cars to Damsite, at which place the inclined cableway dropped them right down to the floor of Hetch Hetchy Valley. They were given rides on the narrow-gauge Valley Railroad to view the various phases of construction; they saw the never-ending streams of concrete flowing down through vast overhead pipes and chutes. Some of the Yosemite parties stayed overnight at the Park's Hetch Hetchy Lodge at Mather. Those who went directly back to Yosemite Valley arrived in the evening—it was a rugged day of sightseeing, but people thought much less of discomfort in those days.

Upon completion to its initial height in July, 1923, the dam was dedicated and officially named O'Shaughnessy Dam in honor of the chief engineer, and it was acclaimed as the largest single structure on the entire West Coast. This dam impounded 206,000 acre feet of water—an amount adequate to keep the Moccasin Powerhouse in operation continuously and draw in two million dollars annually to help pay for the job. In 1938 the dam was raised 85½ feet and enlarged to its present size: height above bedrock, 430 feet; crest length, 900 feet; base thickness, 308 feet; water impounded, 360,000 acre feet.

There are fourteen outlet conduits with slide gates in the structure through which water from the reservoir can be released. Eleven of these outlets are regulated by manually-operated valves ranging in diameter from three to six feet. The remaining three outlets are connected by a trifurcation and a steel pipe to a tunnel leading to Robert C. Kirkwood Powerhouse, eleven miles downstream in the canyon near Early Intake. The spillway is of side-channel type with three drum gates, each 65 feet long, installed in 1950 to provide additional storage when the reservoir is full. Total cost of the dam, including its enlargement, was $12,600,000.

Canyon Tunnel and Robert C. Kirkwood Powerhouse

The 149-mile aqueduct, transporting water from Hetch Hetchy to Crystal Springs Reservoir south of San Francisco, starts at O'Shaughnessy Dam. A nine-foot steel pipe from the outlet system passes under the Tuolumne River in concrete encasement and connects to Canyon Power Tunnel. This pressure tunnel, driven through solid granite mountains on the north side of the river, carries water eleven miles to Robert C. Kirkwood Powerhouse at Early Intake. It is capable of carrying 550 million gallons of water per day at the pressure of average reservoir elevation.

The tunnel is unlined except in a few places where ground conditions necessitate concrete lining, and at the portals, where steel lining is utilized. Slope of the tunnel is 10½ feet per mile and the unlined section, horseshoe-shaped, measures 14 by 14½ feet high. A concrete-lined, underground surge shaft with demand and rejection galleries rises almost 400 feet from the tunnel near the lower portal. Its purpose is to reduce surges and water hammer caused by sudden changes in load at the powerhouse turbines. A trap inside the lower end of the tunnel catches rock, sand, and debris. This Canyon Tunnel, added many years after the Hetch Hetchy system was put into operation, was completed in 1965 at a cost of $11,000,000.

Early Intake

Originally, water released from Hetch Hetchy Reservoir on its way to San Francisco flowed down the natural bed of the Tuolumne River twelve miles to Early Intake, at which place it was diverted into the Mountain Tunnel of the aqueduct. The water is still passed into the tunnel here, but most of it is now carried from Hetch Hetchy in the Canyon Tunnel, in order to first drop it through the new Robert C. Kirkwood Powerhouse. At the same time, sufficient water is released continuously into the river below O'Shaughnessy Dam to sustain fish life in the original natural riverbed.

The Robert C. Kirkwood Powerhouse was named for the one-time State Assemblyman, State Controller, who was General Manager of Public Utilities for San Francisco from 1959 until his untimely death in 1964. It is the most recently constructed power plant of the Hetch Hetchy Project, completed in 1967. This plant, like the one at Moccasin, generates power by means of water on its way to San Francisco. It is located in the Tuolumne River Canyon, immediately upstream from Early Intake Diversion Dam.

Water flowing out of the Canyon Tunnel drops to the powerhouse through a steel penstock pipe 1600 feet long, with a vertical drop of 1100 feet. The force of the water turns two vertical-shaft turbines, each in turn driving a water-cooled generator rated at 33,750 kilowatts at 13,800 volts. Power is stepped up to

Inclined railway led from railroad down to camp and tunnel site at Early Intake

South Fork tunnel, pipe across river here later joined tunnel sections

Penstock from Canyon tunnel leads to powerhouse below (Ted Wurm)

230,000 volts through transformers and transmitted three-quarters of a mile downstream to Intake Switchyard. The power plant, like Dion R. Holm Powerhouse on the Cherry, is operated by remote control from Moccasin Powerhouse several miles to the west.

After doing its work in the powerhouse, water is carried through a short tunnel and pipe conduit into the old Mountain Tunnel of the original aqueduct construction. The water may also be discharged into Early Intake Reservoir, when tunnels are shut down for inspection and repair. The power plant with its penstock and equipment represents an investment of $9,000,000.

The diversion dam at Intake, completed in 1925 to turn waters from the riverbed into the Mountain Tunnel, is a thin concrete arch 262 feet long and 81 feet high, above bedrock, with a thickness of 16 feet at the base. At the left bank (looking downstream) is the intake structure for the Mountain Tunnel; on the other bank is a five-section spillway. Upstream water surface is automatically maintained at a constant elevation.

A short distance downstream from this diversion dam was the first powerhouse, the tiny Early Intake Powerhouse built in 1918 to generate electric energy for the builders of the initial phase of Hetch Hetchy. All materials and equipment for this powerhouse, for the three-mile aqueduct feeding it, for the building of the diversion dam, and for the start of the Mountain Tunnel westward, had to be delivered to the bottom of the steep Tuolumne River Canyon here—to say nothing of workmen and their quarters, food, and supplies for many years.

The Hetch Hetchy Railroad was handy, but it was 1900 feet higher, up there on the cliff! The steep, narrow road was inadequate, so an inclined tramway was built right down the side of the canyon. It operated like a super outdoor elevator, with electric motor, a steel cable, and a signal wire strung alongside. Right at Intake railroad station it started down and came to a stop near the tunnel mouth below, alongside the river. Most of the materials were carried on this—as planned, most of the loads were going downhill! This tramway served the camp and the small powerhouse, carried food and mail, materials for the extensions and improvements, and passengers for nearly forty years.

Mountain Tunnel

Water diverted into the aqueduct at Early Intake, either from the Tuolumne River at the dam or from Robert C. Kirkwood Powerhouse, flows through the 19-mile Mountain Tunnel to Priest Reservoir. The long tunnel has a slope of eight feet to the mile and is generally of horseshoe shape. About 38% is bored through solid granite and is not lined, having a diameter of about 13½ feet. The remainder is concrete-lined, to a ten-foot finished diameter. Designed for a flow capacity of 400 million gallons daily, the

tunnel can carry 470 million under maximum flow conditions.

Excavation for the Mountain Tunnel was carried on from twelve working faces simultaneously. Four of these were portals—the tunnel was briefly broken where it crossed the South Fork of the Tuolumne—four more were from two adits coming in horizontally from the canyon side. The final four were in both directions from the bottoms of two deep shafts: Big Creek, 646 feet, and Second Garrotte, 786 feet. Underground crews at the Priest Portal face established the United States hard-rock tunnel record for the time; they drove 776 feet of tunnel in one month. (By way of contrast, crews excavating the Canyon Power Tunnel in the early 1960's, forty years later, averaged over 1700 feet per month for considerable periods of time—but the earlier record is still impressive, considering the tools and materials available.) Work on the Mountain Tunnel was started in 1918 and completed in 1925, $11,500,000 being expended on the job.

At one point the tunnel crosses the famous Mother Lode gold-mining belt, two miles wide. The tunnel itself proved a latter-day gold mine for the Groveland area, with several construction camps nearby and headquarters right in town. Memories of Saturday nights in Groveland fill the stories of old-timers who worked on the project or who were permanent residents of the region. Upon completion, the tunnel was used initially only for the operation of Moccasin Powerhouse, as explained above, and helped earn about two million dollars a year for bond retirement and interest. When the aqueduct was completed to the Bay Area in 1934, the tunnel became the first stage of the "closed circuit" carrying water to San Francisco.

Priest Dam, Reservoir and Power Tunnel

At the west end of the Mountain Tunnel, 19 miles from Early Intake, water enters Priest reservoir, the forebay for Moccasin Powerhouse. Its function is to temporarily store the inflow from the tunnel, which is at a constant rate, and to release water to the powerhouse at a variable rate, depending upon power generation requirements.

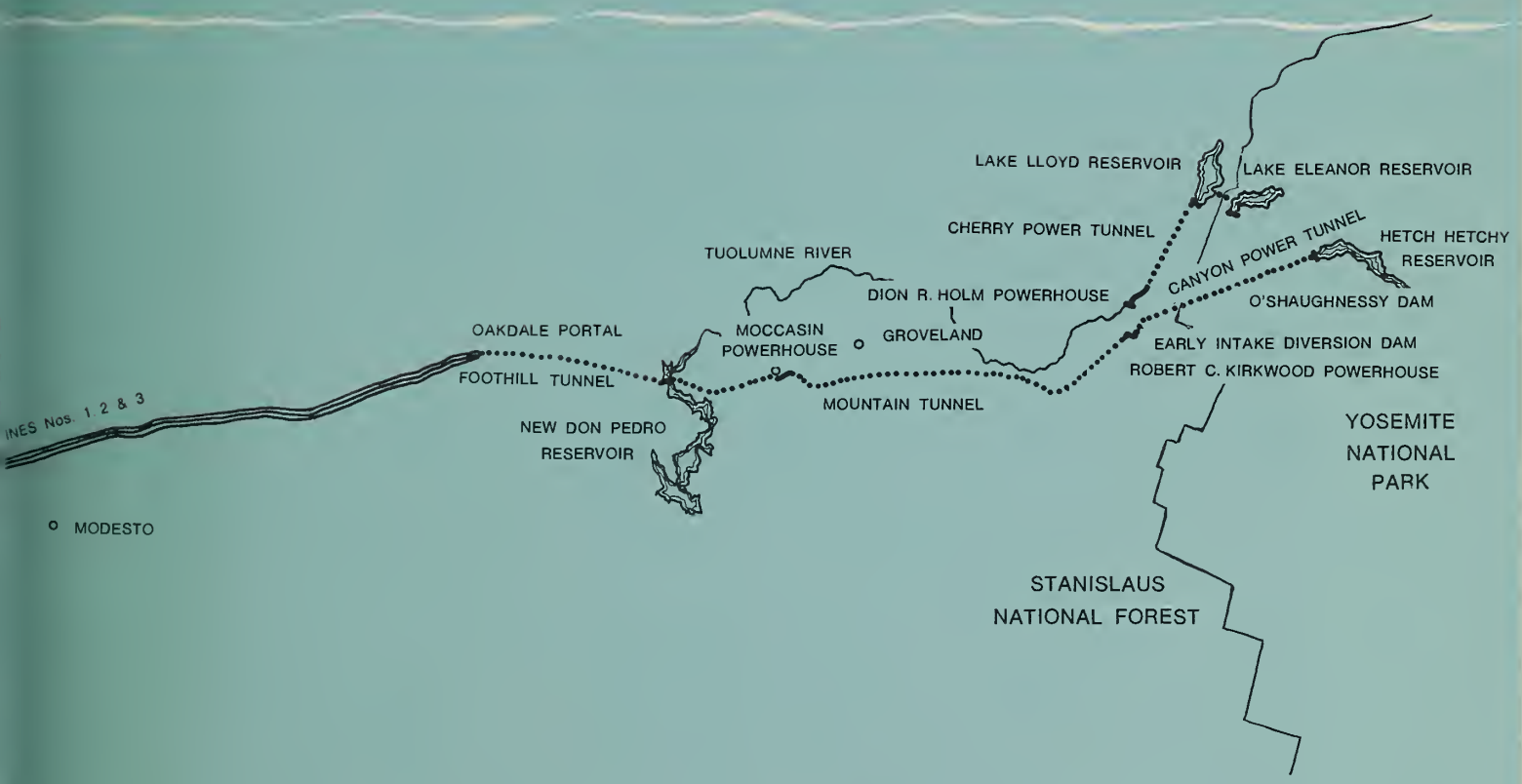
This reservoir, near the top of Priest Hill, was formed by the construction of a hydraulic- and earth-fill dam, with concrete core wall, across Rattlesnake Creek, a tributary of Moccasin Creek. The dam is 148 feet high, 1600 feet long, and 660 feet thick at the base. A concrete-lined spillway protects against overtopping and a tunnel through the left abutment serves as an auxiliary outlet for draining the reservoir. There is a concrete control tower regulating release of water to Moccasin Powerhouse. The flow is through gates in the tower and along a mile-long power tunnel leading to the brow of the hill above Moccasin. Concrete lines this horseshoe-shaped tunnel, which measures 13 by 13 feet and has a capacity of 800 million gallons per day. A surge shaft 160 feet high rises above the hill near the downstream end of the tunnel.

Dam at Priest Reservoir was earth-fill type

Workmen drill and blast as aqueduct tunnel advances westward

Penstock pipes carry water in 1300-foot drop into Moccasin powerhouse for generation of electricity

Carrying Water to San Francisco



Carrying Water to San Francisco

One hundred and forty-nine miles long, the Hetch Hetchy Aqueduct carries pure water from the Sierra Nevada Mountains to San Francisco and neighboring cities, generating electricity in the process. The flow is entirely by gravity.

Huge steel penstock pipes extend from the west portal of the power tunnel and literally throw themselves down the steep slope of Priest Hill, a vertical drop of 1300 feet in about one mile of pipe length. The tunnel portal has connections for three penstock pipes, one of which is capped for possible future enlargement of the plant. At present, two 104-inch pipes begin the descent, soon branching into four smaller pipes for the main drop, and then near the bottom into eight 36-inch pipes, which enter the powerhouse. The lines are supported on concrete piers and held by huge concrete anchors.

Moccasin Powerhouse, Reservoir, and Dam

The powerhouse on Moccasin Creek was placed in operation in 1925. Designed in early Spanish Mission style, with tile roof and wide arcades, the plant was placed in a pleasant, small valley, just across from the Mother Lode stagecoach road, now California Highway 49. This location was an important stage junction in early days, the spot at the foot of infamous Priest Grade where the Big Oak Flat Road headed into the mountains for Yosemite.

Clustered around the big powerhouse are the dwellings, offices, and shops of the "town" of Moccasin, property of the City and County of San Francisco and headquarters for construction and maintenance of the entire Hetch Hetchy Project. During its first years, the site was served by a 7000-foot spur running down from the Hetch Hetchy Railroad, which slowly drew itself up the mountain on its way to higher elevations. The superintendent at Moccasin also serves as unofficial "mayor" of the pleasant, tree-shaded settlement, which lies about twenty miles south of Sonora.

Hetch Hetchy water, racing at tremendous pressure out of the eight final sections of penstock, turns four massive generators each with two impulse-type water wheels on horizontal shafts. The powerhouse has four 11,000-volt, 17,500-kilowatt, air-cooled generators. Power from each generator is stepped up to 115,000 volts through transformers, which feed the power into the Moccasin-Newark transmission line for delivery to consumers.

Moccasin Powerhouse, with its feeder tunnel and penstocks, cost just over six million dollars when it was activated in 1925. In 42 years of operation the plant had produced a total of $115,000,000 worth of power for the City of San Francisco, when ground was broken in 1967 for a replacement. The new outdoor-type plant was designed to incorporate the most modern machinery, with an initial installation of two generators of 45,000 kilowatt capacity each, and is immediately adjacent to the old building so that the same penstock lines can be used. $250,000 more income will be realized each year with the two new generators than the old powerhouse was able to generate with four.

The small lake in the valley, right in front of the Moccasin Powerhouse, is actually a reservoir which serves as the powerhouse afterbay. Since the rate of water flow through the plant varies during the day according to power needed and generated, the purpose of the afterbay is to provide regulation for uniform flow in the aqueduct carrying water westward on its way to San Francisco.

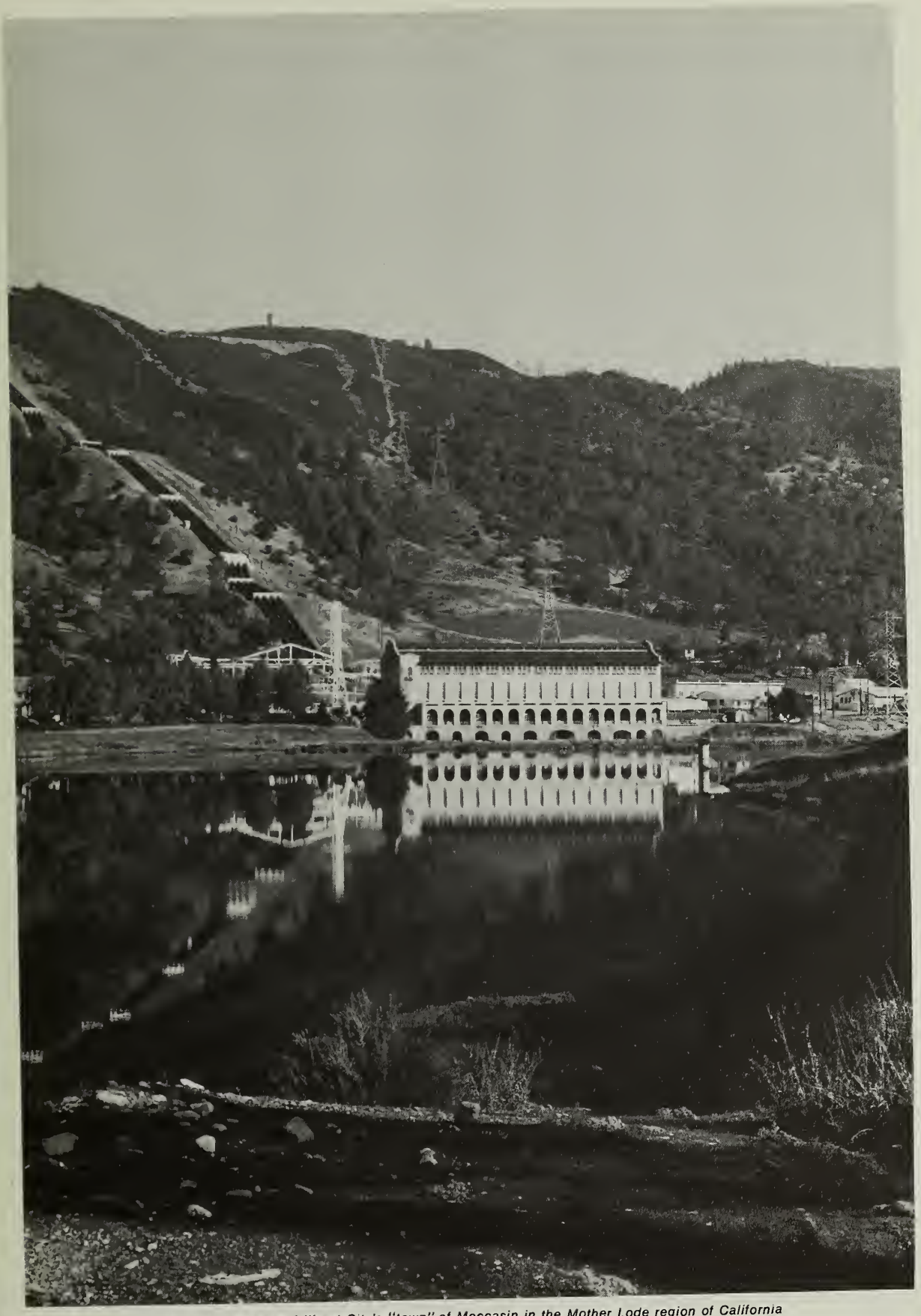
An earth-fill dam, fifty feet high and 855 feet long, was thrown across Moccasin Creek to create this reservoir. At a later date it was necessary to build another dam upstream from the reservoir—this one a concrete dam 321 feet long and designed, strangely enough, to keep water OUT of the reservoir! This came about because the watershed of Moccasin Creek above the area contains sources of contamination, and flood waters of the creek are extremely muddy and full of debris. So it is necessary to exclude these waters from the clean supply flowing out of the powerhouse and into the next tunnel.

The upstream dam at Moccasin—seventh to be built in the Hetch Hetchy Project and last one in the initial development phase—diverts creek water through a bypass tunnel laid on the floor of the reservoir. The potentially-polluted water flows for 2900 feet through this tunnel and is discharged below the downstream dam, where it continues down the original Moccasin Creek bed. In the meantime, the water for San Francisco passes out of the reservoir above into the Foothill Tunnel of the aqueduct. The Moccasin Reservoir system of dams and diversion appurtenances was completed in 1936 at a cost of $900,000.

Foothill Tunnel and Don Pedro

The water aqueduct continues westward from Moccasin in an entirely-closed conduit for the next 116 miles to Crystal Springs Reservoir, just south of San Francisco. The first part is a sixteen-mile tunnel through the foothills on the east side of San Joaquin Valley. This tunnel extends from Moccasin Reservoir to a connection with the great valley pipelines at Oakdale Portal, south of the historic town of Knight's Ferry. First step was to close the construction headquarters at Groveland and move shops, equipment, offices and dwellings to a narrow, sun-baked canyon called Hetch Hetchy Junction—the starting point of the Hetch Hetchy Railroad, at the point where it took off from the Sierra Railway. This was an ideal point for supply and communications and would be the location of one of the shafts for the tunnel work.

Headquarters was established at "The Junction" in November, 1925, and first work on this part of the aqueduct was the opening of Pedro Adit above the Tuolumne River canyon early in 1926. Miners were soon drilling and blasting the tunnel out from ten faces or construction points—four of these from the two shafts at Hetch Hetchy Junction and Rock River, two from the portals, and two each from Pedro Adit



Powerhouse is center of life at City's "town" of Moccasin in the Mother Lode region of California

and Brown Adit. Five miles west of Moccasin, the tunnel was broken by the river canyon at Red Mountain Bar. Here the half-mile crossing was accomplished by means of an inverted siphon—a 9½-foot steel pipe embedded in concrete.

The Red Mountain Bar siphon would not actually be required to carry water for several years, but the river channel at this crossing was due to be flooded by the waters of the then-building Don Pedro Reservoir. The dam for Don Pedro was a few miles downstream from this point; it was a project of the Modesto and Turlock Irrigation Districts, completed at the same time as O'Shaughnessy Dam. Since the Hetch Hetchy siphon would be under 80 feet of water at Red Mountain Bar, the lower portion was constructed in advance of the filling of the reservoir.

During the years of tunneling in the Foothill Division, which was the section westward from Moccasin, a novel transportation system was rigged up from the railroad at Red Mountain Bar to reach the tunnel work at Brown Adit to the east. Roads into the Brown site were extremely difficult for the trucks of that period, so a narrow-gauge rail line was laid in from the east side of the Tuolumne River a mile and a half to Brown and right on into the tunnel itself.

On the opposite side of the river canyon a railroad siding was built beside the Hetch Hetchy Railroad main line. Over the canyon from here was installed a Lidgerwood-type, steel cable "high line" a half-mile long, capable of carrying five-ton loads of supplies and passengers right to the tramway across the river. It was reported at the time that this set a world record for length of span for a cableway of the hoisting and conveying type. It took two minutes to make the aerial journey across Don Pedro Reservoir.

Half the length of the Foothill Tunnel is a concrete-lined horseshoe section, ten feet in diameter, and the balance is unlined and measures 13½ feet by 14½ feet high. The tunnel slopes 8.2 feet per mile and, like the Mountain Tunnel, can carry in excess of 400 million gallons a day. The work on this tunnel was originated at all six camps by City forces, then three camps were turned over to contractors who made successful bids. This proved to be a wise policy, as initial work by the City insured reasonable bids and a spirit of competition between the City's forces and those of contractors working in adjacent sections. At the same time, a direct comparison of costs was made possible.

In vanquishing the crews of private contractors, the City miners set a new Hetch Hetchy record for one month's progress in excavation—781 feet at Hetch Hetchy Junction east heading. Six months later, in September, 1927, the record was broken again in the same heading, the new figure being 803 feet, which also established a new national record for such work! The tunnel was completed in 1929 at a cost of $8,000,000.

San Joaquin Pipelines

The San Joaquin Valley is the southern portion of the great Central Valley of California. This valley is crossed by the Hetch Hetchy Aqueduct, the water being carried in three underground pipelines, which were constructed at various times as the demand for transmission capacity increased. These pipelines lie within a 100-foot right-of-way, which has space for a future fourth line.

Water is carried in these pipes, under pressure, all the way from the Foothill Tunnel at Oakdale Portal, to the Coast Range Tunnel at Tesla Portal, near Tracy —a distance of 47½ miles. The lines reach a point below sea level where they pass under the stream bed of the San Joaquin River, a navigable stream. Here and at nearby Elliott Cut the pipes are supported on concrete saddles supported by timber piles and encased in reinforced concrete jackets. Flow in all three lines is regulated by valves at Oakdale Portal.

The first pipeline was started in 1931 and completed a year later. It consists of welded and riveted steel pipe, varying from 57 to 72 inches in diameter, each section coated with hot dipped asphalt and wrapped in asphaltic felt. Pipeline No. 2 has an inside diameter of 61 inches throughout its length and consists of 28½ miles of welded steel pipe, coated and lined with cement mortar, and 18½ miles of reinforced concrete pipe. This line was completed in 1953 and enabled the shutting down of the first pipe so that its interior asphalt coating could be removed and replaced with cement-mortar lining. The first pipeline cost $5,000,000 and the second $12,300,000.

A third San Joaquin Valley pipe, built in two stages as need developed, is of welded steel with coal-tar enamel coating. East of the San Joaquin River the pipe is lined with cement-mortar and measures 78 inches in diameter; west of the river, lining is coal tar enamel and the measurement increases to 79½ inches. On all three pipelines there is an automatic pressure relief valve at the river crossing, which discharges water into the San Joaquin should excessive pressure develop. Total capacity of the pipelines is 295 million gallons per day, which is estimated to be sufficient for the system's requirements until the year 1980.

Coast Range Tunnel

The 29-mile section of the aqueduct through the Coast Range Mountains extends from Tesla Portal, south of Tracy, to Irvington Portal, near Mission San Jose in the City of Fremont. It consists of a 25-mile continuous tunnel, which was the longest in the world when completed, and a 3½-mile tunnel. These two segments are connected by a multiple-pipe, inverted siphon a half-mile in length, across the valley of Alameda Creek. Connections are made at this siphon to transport water from the Alameda County sources—formerly parts of the Spring Valley

City officials at final "holing through", January 5, 1934. (Back row) Nels Eckart, Les Stocker, M. M. O'Shaughnessy, Mayor Angelo J. Rossi, Lewis F. Byington, George Filmer, T. W. Espey, J Emmet Hayden (Standing) George W. Pracy, Edwin Eddy, Frank Purdue, Edward J. Cahill

San Joaquin pipeline under construction in 1966

Water Company—of the San Francisco Water Department through the Hetch Hetchy Aqueduct.

The tunnel is circular, 10½ feet in finished diameter, with concrete lining varying in thickness from six inches to three feet. With the grade of 2.64 feet per mile, it would have required a tunnel thirteen feet in diameter to carry 400 million gallons daily. The Mountain and Foothill tunnels meet this requirement, but for economy reasons it was necessary to build the Coast Range Tunnel "on the installment plan," with the present portion able to handle over 275 million gallons and a second tunnel to be built 175 feet south at a future date, when the first is nearing its capacity.

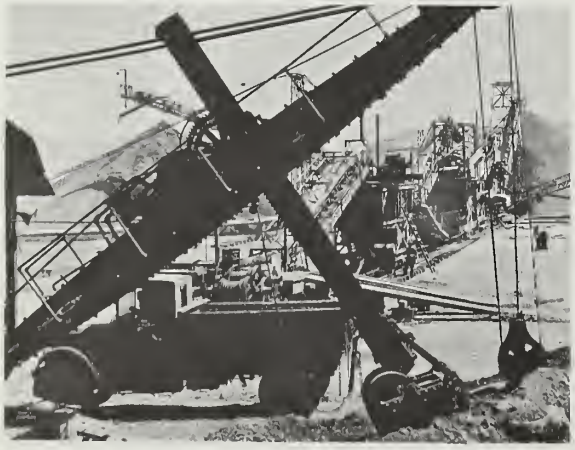
In the 25-mile section, five shafts were sunk, varying in depth from 254 to 823 feet. These shafts, together with the four portals, or tunnel entrances, provided fourteen construction points, or faces, from which material was excavated. At each shaft a crosscut was driven at right angles 95 feet to the center line of the present tunnel and 80 feet to that of the future tunnel. The shafts and crosscuts were concrete lined, to keep them in condition for use in building the second tunnel. From the north end of each crosscut the tunnel was driven in both directions. Work was started in 1927 with City crews doing the work and all power supplied from the system's Moccasin Powerhouse.

Hazardous working conditions had been anticipated—in fact, some engineers and political factions wanted to have the water pumped over the Coast Range to save time and the expense of tunneling. But O'Shaughnessy showed that a pipeline for 60 million gallons per day, plus the cost of pumping would tie up nearly as much capital as the 200-plus-gallon tunnel besides which the pipeline would have to be added to in twelve years and the pumping expense would go on forever!

The hazardous conditions included dangerous explosive gases, ground water, quicksand, and swelling ground. The latter was particularly troublesome where the tunnel passes under Crane Ridge at a depth of 2500 feet below the surface. The bore in this zone was eighteen feet in diameter, solidly supported by 18-inch square timbers, and this, during one period of 24 hours, squeezed in three feet all around, reducing the heavy timbers to kindling wood. In just a few days the tunnel had become so small that a person could crawl through on hands and knees only with difficulty. It was impossible to gunite by the usual method, because the quick squeezing wouldn't allow the cement to set.

A new system of ground support was tried and proved very successful. The tunnel was excavated oversize so that when the gunite was placed, there was a space of about one foot into which the ground might swell without putting any pressure until the cement was set and had developed sufficient strength.

Coast Range Tunnel, world's longest when completed in 1934



Above Tunnel machinery prepares concrete for tough lining job

Bay Crossing pipelines 1 and 2 in Southern Alameda County

Pipelines on Dumbarton Bridge carry water across S. F. Bay

The lining was 2½ to 3 feet thick and mixed with a very high cement content. The gunite lining withstood the enormous pressure exerted by the swelling ground, even in places where the tunnel passes directly through the fractured junction of two earthquake fault lines. The earthquake threat was known to the engineers—opponents had been issuing warnings for years—and they designed means to cope with it. Some sections of the concrete lining have flexible joints for this purpose. Periodic inspections over more than thirty years of constant use show the tunnel to be virtually as sound as on the first day it carried water.

Cost of the Coast Range Tunnel was $28,000,000, some of which was so hard to obtain at different times during the depression years that several of the headings were shut down for varying periods of time. This was to "conserve funds," as documented in the 1930 annual report, "pending the sale of bonds to finance the work . . ." At the conclusion of this phase of the Hetch Hetchy Project, the audit showed a saving of over a million and a half dollars through having the work done by the City's Construction Division instead of the next lowest bidder. The San Francisco working forces had bid a half million dollars lower, and still finished the job with over a million dollars not needed!

Bay Division Pipelines and Pulgas Tunnel

From Irvington Portal, at the west end of the Coast Range Tunnel, four pipelines convey water from Hetch Hetchy and Alameda County sources through the southern end of the Bay Area and through Redwood City to Pulgas Tunnel. The first two pipelines, 21 miles long, cross San Francisco Bay at Dumbarton Strait. Lines 3 and 4, 34 miles in length, take another route which passes around the southerly end of the bay. Separation of the two pairs of lines reduces the possibility of simultaneous loss from damage by earthquake or other causes. The pipelines are riveted steel, welded steel, and steel cylinder reinforced-concrete pipe.

Nearly all of Line 1 is 60 inches in diameter except for a half-mile of 42-inch, flexible-joint cast iron pipe, which is laid in a trench below the mud and water under Newark Slough and a navigable channel of the bay. This was one of the first parts of the Hetch Hetchy Aqueduct put in service, being completed in 1925 at a cost of $6,000,000, and was leased immediately to Spring Valley Water Company to augment their own small line in transporting Alameda water supplies to the City. At the time this line went into service there were only 70 days' supply of water in Spring Valley's Peninsula storage.

Line 2 is largely 62 and 68 inches in diameter, except for two parallel underwater pipes a half-mile in length, each 54-inch welded steel pipe encased in concrete and supported on piling. West of the channel the three submarine sections of Pipelines 1 and 2

Pulgas Water Temple marks end of 149-mile Hetch Hetchy Aqueduct at Crystal Springs Reservoir

enter a concrete caisson from the bay bottom. Connecting pipes rise vertically to emerge through a manifold from which the two pipelines are carried to the west shore on a steel truss bridge three-quarters of a mile long. Bridge piers and caisson are of reinforced concrete, supported on piling. $4,000,000 was the additional cost of the second line, which was completed in 1936.

Pipeline 3 averages from 72 to 78 inches in diameter and was placed in operation around the end of the bay in 1952 at a cost of $10,000,000. The fourth line has a pipe of 90 and 96 inches, completed as far as Stanford Tunnel in 1966 and set for completion to Pulgas Tunnel in 1969. The total capacity of the Bay Division system will be over 300 million gallons per day.

From the westerly end of the bay pipelines, in the hills behind Redwood City, water flows 1.7 miles through Pulgas Tunnel and discharges through an outfall canal into Upper Crystal Springs Reservoir, the terminus of the Hetch Hetchy Aqueduct. Pulgas Tunnel was completed in 1924 and carried Spring Valley water under a lease agreement until the City purchased the private system in 1930. Water from the Sierra Nevada first reached this point, the end of the line, on October 24, 1934.

Eighty-nine men had lost their lives in getting the water to San Francisco. Michael M. O'Shaughnessy, the engineer who had seen the project through twenty years of building and was scheduled to be the honored guest when the water arrived, passed away suddenly just twelve days before, at the age of 70.

San Francisco spokesmen were able to make a striking comparison when the Hetch Hetchy was completed. They pointed to the great and celebrated Catskill Aqueduct serving New York City. The latter had been hailed upon completion in 1924 as the most stupendous engineering project ever completed, including the Panama Canal! Yet, in 1934 Hetch Hetchy surmounted the Catskill in length of aqueduct, length of tunnels, capacity of aqueduct, and capacity of reservoirs!

Marking the terminus of the 149-mile system is Pulgas Water Temple, an ornamental structure of cast stone and concrete with a reflecting pool. Inscribed thereon is the scriptural quotation:

"I give waters in the wilderness and rivers in the desert, to give drink to my people." (Isaiah 43:20)

A five-mile additional aqueduct, consisting of a tunnel and steel pipeline, is being constructed between an angle point near the west end of Pulgas Tunnel and a point near the intake of the Crystal Springs Pipelines which carry water to San Francisco. This connecting line will bypass Crystal Springs Reservoir and permit delivery of water from Hetch Hetchy and Alameda County sources by gravity directly into the City. Such arrangement will allow longer retention of water in the reservoir when made necessary by turbid conditions resulting from local run-

off, will reduce exposure of Hetch Hetchy water to local algae conditions, and, in the event of contamination of the Peninsula reservoirs by radioactive fallout or other causes, will permit Hetch Hetchy water to be delivered directly without passing through these storage facilities.

Additional Components

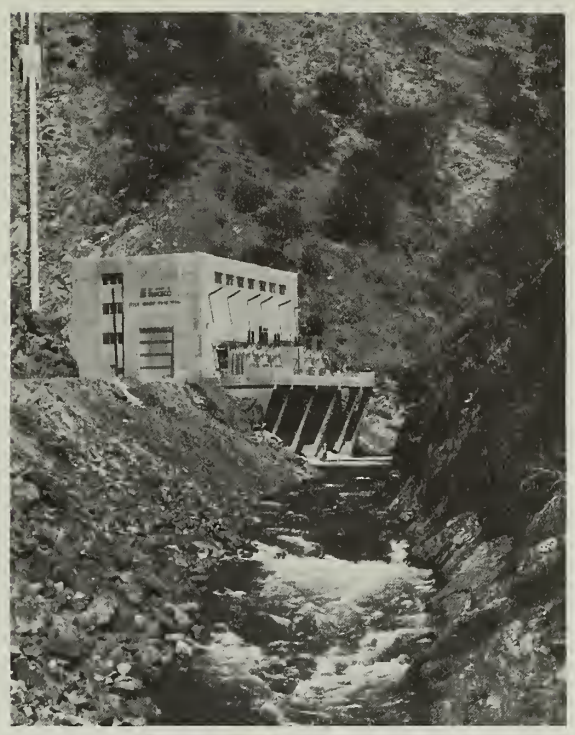
Cherry Valley Dam and Lake Lloyd

Hetch Hetchy Water had barely reached the taps of San Francisco in 1934 before the City's engineers were back in the mountains of Tuolumne County working on increasing the height of O'Shaughnessy Dam and adding thereby to the storage capacity in Hetch Hetchy Reservoir. This job, in turn, was scarcely brought to a successful conclusion in 1938 before they were packing their instruments again and heading northwest from Hetch Hetchy about 17 miles to the valley of Cherry River, at a point where a third impounding reservoir had been authorized by the Raker Act.

This additional storage had been planned to provide for expanding water supply needs and to develop additional electric power resources. Beginning in 1939, extensive studies on the development and conservation of the waters of the Tuolumne revealed a number of mutual interests. San Francisco required additional storage capacity in the mountains to assure its water supply. The Turlock and Modesto irrigation districts in the valley desired additional storage to provide for increasing irrigation use and to minimize water shortage in dry years. Both the City and the districts could use additional stored water for electric power generation, the revenue from which would defray costs of required storage reservoirs. The Corps of Engineers, U. S. Army, was interested in providing protection from flood damage along the lower Tuolumne and San Joaquin Rivers.

In 1941 crews from San Francisco began survey and other preliminary work in the Cherry Valley area. The City spent $25,000 a year for eight years on this exploratory work, which protected the City's rights and prepared the way on a small but carefully programmed scale until 1949. In that year the four interested agencies signed cooperative agreements which provided that:

1) San Francisco and the districts make certain modifications to their then existing facilities, construct new facilities, and operate both to reserve reservoir space for protection against Tuolumne River floods, in accordance with regulations established by the Corps of Engineers.
2) San Francisco immediately construct a reservoir in Cherry Valley.
3) The irrigation districts, at a later date, develop a new larger reservoir on the lower Tuolumne, below the old Don Pedro Dam, which would



Dion R. Holm powerhouse on Cherry River

Cherry penstock construction in rugged Sierra, 1959

afterward be 200 feet below the maximum water surface line.

4) Upon completion of the latter reservoir, all flood control operations on the Tuolumne River watershed be transferred to the new storage facilities.
5) For flood control benefits, the Federal Government would pay $9,000,000 toward construction of the $13,000,000 Cherry Valley Reservoir and would pay a subsequent amount (about $5,400,000) toward building the New Don Pedro Reservoir.
6) For the right to use a stipulated amount of storage space in the New Don Pedro, San Francisco would pay an estimated $45,000,000 toward its construction.

Work on the Cherry Valley Project commenced in 1950 under the direction of Oral L. Moore, Construction Engineer, and, since 1961, General Manager of Hetch Hetchy,Utilities Engineering Bureau. Some 26 miles of access roads were built through rugged Sierra mountain canyons and over ridges in order to carry heavy equipment to the job site. Preliminary construction included a ten-mile, wood-pole power line from the old Early Intake Powerhouse and a 17-foot-diameter, quarter-mile-long diversion tunnel around the damsite. Completed in 1956, the huge Cherry Dam is a composite earth and rock embankment 2600 feet long, with a height above bedrock of 330 feet and a base thickness of 1320 feet. The central impervious core is composed of compacted decomposed granite. The diversion tunnel has been made into a permanent outlet and there is another consisting of a six-mile power tunnel to Dion R. Holm Powerhouse on the Cherry River near its confluence with the Tuolumne.

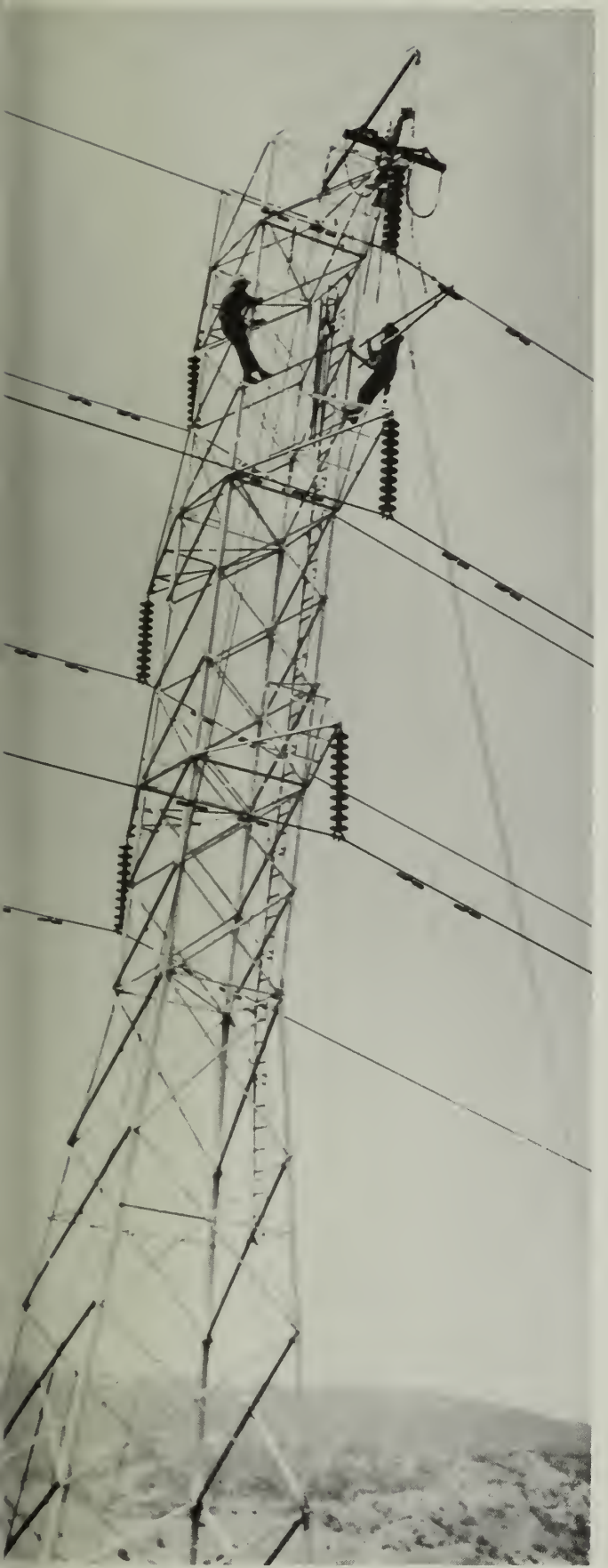
The reservoir formed behind Cherry Valley Dam has been named Lake Lloyd in honor of the then Manager and Chief Engineer of the Hetch Hetchy Department, Harry E. Lloyd. This reservoir provides multi-purpose storage for conservation, flood control, and power generation, but the impounded water does not contribute directly to San Francisco's domestic water supply. Releases from Lake Lloyd are used for power generation at Dion R. Holm Powerhouse and for meeting down-stream irrigation priorities under the Raker Act, thereby preserving storage in Hetch Hetchy Reservoir for the City's domestic supply. In 1960 a mile-long tunnel was driven through the ridge between Lake Eleanor and Lake Lloyd, enabling runoff from Eleanor watershed to supplement storage in the Cherry system.

Dion R. Holm Powerhouse

Largest power plant on the Hetch Hetchy system is the Dion R. Holm Powerhouse, named in honor of the late City Attorney Dion R. Holm, long-time counsel to Hetch Hetchy in its early years of operation. This powerhouse was completed in 1960 on the Cherry River, six miles downstream from Cherry Valley Dam. Runoff from Cherry River watershed, together with water diverted from Lake Eleanor, is used to operate this plant. A six-mile pressure tunnel leads from the reservoir—a tunnel bored through granite in 12 by 12½-foot horseshoe shaped, mostly unlined. The tunnel has a 400-foot tall surge shaft and a rock trap near the downstream portal. At this point water leaves the tunnel through an eight-foot diameter butterfly valve and drops down the mountainside to the powerhouse in a single, steel-pipe penstock—a vertical distance of 2100 feet. The pipe is 6700 feet long, tapering in diameter from 7½ feet at the top to 5 feet at the powerhouse. In order to sustain the high pressure, the pipe is fabricated out of steel plate increasing in thickness from ¾ inch at the top to 2½ inches at the bottom of the penstock! Inside the powerhouse are two vertical-shaft, turbine-driven generators, each with a rating of 67,500 kilowatts. Voltage is stepped up to 230,000 volts for transmission of power one and a half miles to Intake Switchyard, where power from the nearby Robert C. Kirkwood plant also joins the system.

Normally, this powerhouse on the Cherry, like the Robert C. Kirkwood Powerhouse near Early Intake, is operated by remote control from Moccasin Powerhouse, some twenty miles away. By push-button operation generating units are started and stopped, speed and voltage are adjusted, readings taken, and switching performed. The control room at Moccasin is a fascinating place and visitors marvel at the quiet efficiency of operators surrounded by literally hundreds of dials and gauges which tell them exactly what is going on at three large power generating plants and all along the lines carrying the power from these plants. Water passing through Dion R. Holm Powerhouse discharges into Cherry River and continues down the Tuolumne River to Don Pedro Reservoir, operated by the irrigation districts. The cost of this plant, including tunnel, penstock, and all equipment except transmission lines, was nearly $25,000,000.

The development of Dion R. Holm Powerhouse and its neighbor, Robert C. Kirkwood, was postponed for many years. Both were completed in the 1960's, many years after the initial power plants at Early Intake and Moccasin. It was not until after San Francisco had worked out a plan for disposal of the electric energy acceptable under provisions of the Raker Act, that the two additional powerhouses were constructed. The City does not own a municipal electric distribution system, but delivers the bulk of its energy, at transmission voltages, to other agencies for direct sale or for transporting to the City's municipal loads and customers under contractual agreements.



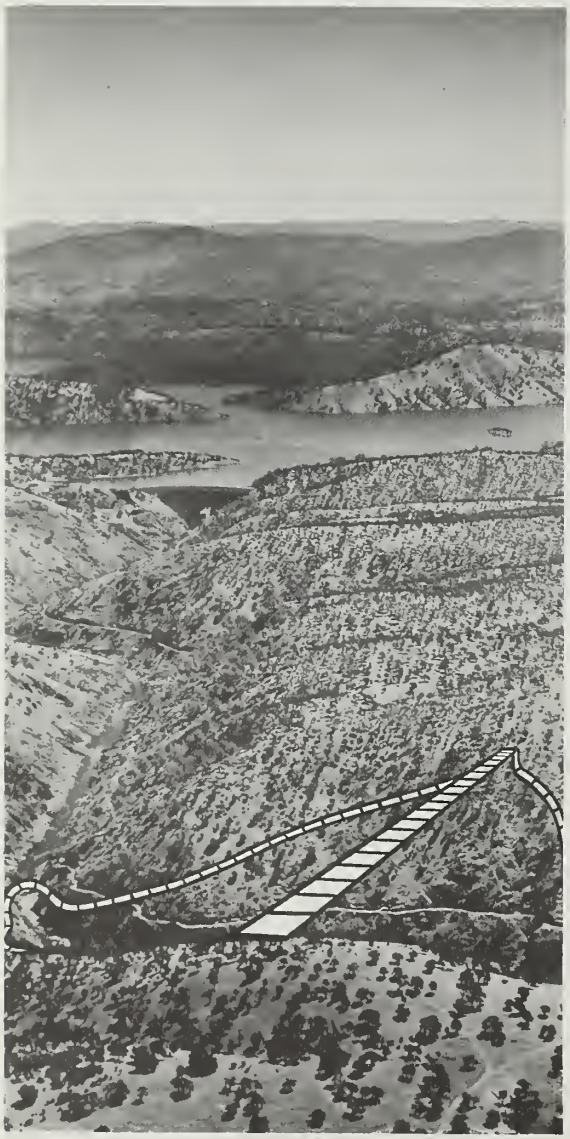
Power Transmission Lines

Electric energy generated by Hetch Hetchy power plants is carried to points of delivery over two high voltage transmission systems, normally operated independently of each other. Each system includes the lines, plus switchyards, substations, oil circuit breakers for high voltage switching, transformers for stepping up the voltage required for transmission, and automatic protective equipment. These two circuits are interconnected with the electric power systems of Turlock Irrigation District, Modesto Irrigation District, and the Pacific Gas and Electric Company.

From Moccasin Powerhouse switchyard, electric energy is carried over the Moccasin-Newark line, which crosses the Sierra foothills, the San Joaquin Valley, and the Coast Range Mountains to the Newark Substation of Pacific Gas and Electric in southwest Alameda County, near the shore of San Francisco Bay. Built in 1924-25 with two three-phase circuits (six wires), the line operates at 115,000 volts for a distance of 98½ miles. 506 steel towers carry the wires, most of the towers 97 feet tall; at the crossing of the San Joaquin River, special 208-foot towers are used. This line generally follows the same right-of-way as the water tunnels and pipelines as far as Tesla in the Coast Range. Each circuit of the Moccasin-Newark line is connected by taps to substations of the irrigation districts.

It was on this line that the late Art Crowley, in charge of its maintenance for many years, developed methods and tools which were to make San Francisco's transmission line world-famous—tools that are now used all over the world. Before, it had been necessary to cut off current while repairs were being made or improvements installed. No one in his right mind would go anywhere near a 115,000-volt line while it was "hot." But Crowley's tools and methods made this an everyday job, saving millions of dollars through the avoidance of shutdowns and virtually eliminating accidents.

The power from Dion R. Holm and Robert C. Kirkwood powerhouses leaves Intake Switchyard on another steel tower transmission line, this one of 230,000 volts, double-circuit. It carries the power 48 miles, by way of Moccasin, to Warnerville Substation near Oakdale. Here the voltage is reduced to 115,000 for further transmission over a 12½-mile line to Oakdale Substation of the Turlock District and Station "J" of the Modesto District. Warnerville also serves as a point of interconnection with the 230,000-volt system of Pacific Gas and Electric.



Location of new Don Pedro Dam sketched in foreground; old Dam upper left will be under water of new reservoir. (Modesto and Turlock Irrig. Districts)

New Don Pedro

Under the cooperative agreements of 1949, previously mentioned, the Modesto and Turlock Irrigation Districts went ahead with their plans to build a massive new dam about a mile and a half downstream on the Tuolumne from their old Don Pedro Dam of 1923. When the latter was dedicated, it was the highest dam in the world and its builders in their wildest dreams could not possibly have guessed that less than half a century later it would lie 200 feet below the surface of the tremendous new reservoir having a dam 580 feet high and 800 feet long. The old-timers would have argued that a reservoir capacity of over two million acre feet would never be possible at this location. But it has been proven feasible and the reservoir line extends for 24 miles—far beyond Jacksonville, up the canyon beyond Ward's Ferry Bridge, and reaching up Moccasin Creek as far as the state fish hatchery near Moccasin Powerhouse!

So it happens that fifty years later it will be a reality—a great new dam filled with earth and rock which changes the appearance of a vast area of southwestern Tuolumne County. San Francisco's participation in the project—estimated at $45,000,000—was authorized by the electorate in their approval of the 1961 Municipal Water System Bond Issue. The new reservoir provides the City with additional storage space of 570,000 acre feet, plus half of that portion of the 340,000 acre feet of flood control space not reserved for the purpose at any given time. The increase in storage capacity will assure the adequacy of San Francisco's water supply to meet its estimated requirements to the end of the century, without building additional, more expensive storage higher in the mountains. Also, the additional water impounded will safeguard the City's power revenues by assuring full capacity operation of its hydroelectric plants as the amount of water diverted from the Tuolumne watershed to San Francisco increases.

San Francisco Water Department System

General Description

The San Francisco Water Department operation is largely based on the privately-owned Spring Valley Water Company system purchased and taken over by the City in 1930. The subject of acquiring this private utility had been a source of controversy in San Francisco since 1873, when the first attempt was made to purchase it. The voters usually found the offering price higher than they wanted to pay, which is partially why they were eager to seek an independent water supply in the Sierra Nevada Mountains under the leadership of a succession of farsighted mayors and engineers.

At the time the Raker Act was passed in 1913, water was selling in San Francisco for more than 25 cents a thousand gallons and a large percentage of the city's residences were without waterlines, being served out of water wagons. Earlier, at the time of the earthquake in 1906, the private company's lines into town were ruptured, leaving their entirely inadequate local storage supplies unable to fight the great fire that followed.

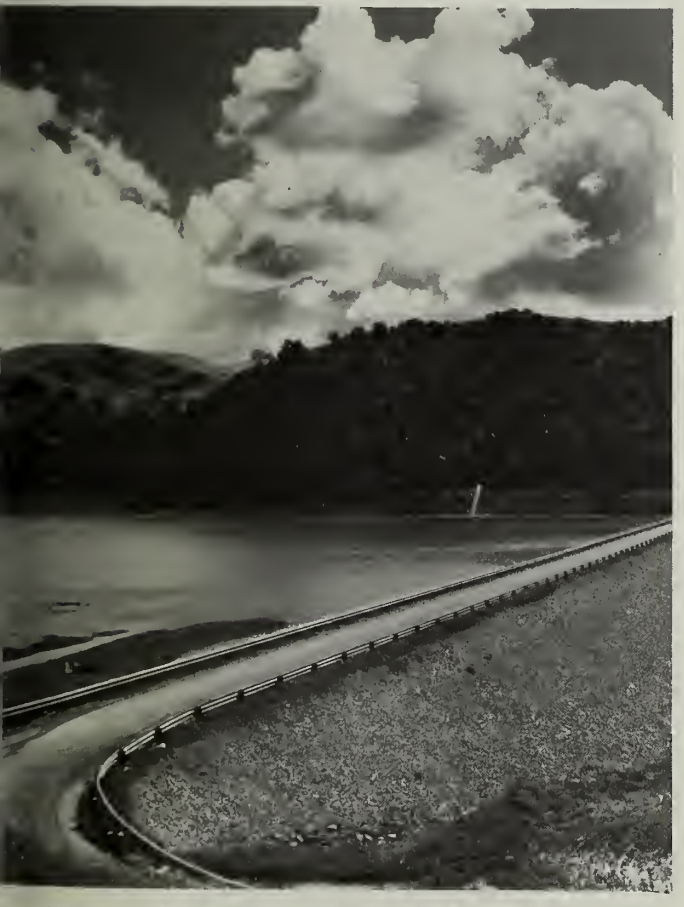
Hetch Hetchy's first Bay Crossing Pipeline saved San Francisco from a water famine when it was rushed to completion and leased to Spring Valley Water in 1925. Voters finally approved purchase of the private system in 1928 and the City took over in 1930, paying $41 million for the water rights, reservoirs and watershed lands, aqueducts and rights-of-way, and the distribution system in San Francisco. For operating purposes the Water Department system is broken down into three divisions: Alameda, Peninsula, and City Distribution.

The Alameda system includes four water-producing units, all located within the drainage area of Alameda Creek in the Coast Range Mountains east of San Francisco Bay. The principal sources of supply here are Calaveras and San Antonio Reservoirs, which are supplemented by two underground sources, the Sunol Infiltration Galleries in Sunol Valley and the Pleasanton Well Field in Livermore Valley.

The Peninsula system, consisting of three reservoirs, transmission mains and pump stations, is located in San Mateo County immediately south of the City and County of San Francisco on the Peninsula. The reservoirs—Pilarcitos, San Andreas, and Crystal Springs (upper and lower)—have a combined watershed area of 32 square miles, which is for the most part covered with a heavy growth of trees and brush.

Making up the City Distribution System are terminal reservoirs receiving water from the Peninsula transmission mains, and the distribution reservoirs, tanks, pumps, and mains delivering water to consumers within San Francisco. The San Francisco Water Department is one of the few major suppliers in the United States which is completely supported by revenues from consumers, with no tax subsidies, hidden or otherwise.

Calaveras Dam Reservoir in Alameda County



James H. Turner Dam impounds water in San Antonio Reservoir

Alameda County Components

Calaveras Reservoir

Lying in both Alameda and Santa Clara Counties, Calaveras Reservoir impounds the runoff of 100 square miles on the slopes of Mount Hamilton, extending up to an elevation of 4,209 feet. In addition to the Calaveras watershed, the drainage from approximately 35 square miles of Upper Alameda Creek is diverted through a two-mile tunnel into the reservoir, the capacity of which is 32.8 billion gallons.

Nine miles south of the town of Sunol is Calaveras Dam, an earth and rock-fill type started in 1913 by Spring Valley Company. After a series of misfortunes and engineering errors, it was finally completed twelve years later, at which time it was the highest earth-fill dam in the world—220 feet above bedrock. The lower portion was built up by hydraulic fill method, and the upper part with a rolled-clay core supported on either side by loosely dumped material containing a large proportion of rock. City Engineer O'Shaughnessy was dubious of plans and construction methods from the start. In a letter of 1913 he wrote, "Unofficially I am going to keep a watchful eye on this proposition so that the City will not inherit a 'gold brick' if it should take this property over." As it turned out, the Spring Valley people eventually had to take the city engineer's advice, thereby avoiding a great tragedy and making this property a valuable addition to the City's water supply.

The dam is 1200 feet long and 1500 feet wide at the base. Riprap on the upstream face consists of hand-placed rock, the upper portion being laid as a series of inclined arches for aesthetic reasons. There are two branches to the outlet tunnel, through one of which water can be released into the stream channel to flow down to Sunol Infiltration Galleries. The second branch leads to an aerating basin having a capacity of 80 million gallons per day. From this point water can be delivered through the 44-inch Calaveras Pipeline by gravity (1) directly to the Hetch Hetchy Aqueduct through a connection at the Alameda Creek siphon, 2) to the aqueduct through the filtration plant, or (3) to the San Antonio Reservoir for storage to conserve local runoff.

San Antonio Reservoir

San Antonio is another reservoir located near the small town of Sunol in Alameda County. This body of water is formed behind James H. Turner Dam, named for a former General Manager and Chief Engineer of the Water Department, Manager and Chief Engineer of Hetch Hetchy, and Manager of Utilities for San Francisco. The reservoir is on San Antonio Creek about three miles southeast of Sunol and impounds runoff from a 40-square-mile watershed, having an annual average runoff of over nine million gallons per day. This facility also provides additional terminal storage for

water from Hetch Hetchy and other sources to assure water service to customers during possible interrupiton of the Hetch Hetchy supply, and to meet high periodic demands in the South Bay Area. Water from San Antonio can be delivered to the aqueduct at Alameda Creek siphon: (1) directly; (2) through the filtration plant; or (3) through the Sunol Infiltration Galleries and Irvington Pumping Station.

The site of this dam was originally selected by the Spring Valley Water Company in 1875. It was mentioned also in the historic 1912 Freeman Report as part of the Hetch Hetchy Project to provide storage adjacent to the main aqueduct. As finally completed in 1965, Turner Dam is a compacted earth-fill structure 195 feet high above streambed, 2160 feet long and 1075 feet wide at the base. The cost, with outlet works, spillway, and other appurtenances, was $6,500,000.

Sunol Galleries and Pleasanton Wells

At the upper entrance to Niles Canyon lies a gravel-filled depression of about 1300 acres known as Sunol Valley, through which the Alameda Creek drainage flows. Below this area, at the entrance to the canyon, a restraining barrier known as Sunol Dam has been built. This is a 28-foot high concrete structure, virtually entirely submerged, which serves to back up the creek flow and keep the gravels flooded. A system of underground concrete galleries and perforated pipe collects the water percolating through the gravel beds, giving a dependable yield of approximately five million gallons daily. Under flood conditions these galleries will produce clear water up to twenty million gallons per day. Sunol Water Temple, a structure of classic design, is erected over the open gathering basin and in this quite lovely spot the Water Department has provided a picnic ground open to the public.

Water leaving Sunol Temple is transmitted five miles through a series of short tunnels and concrete flumes to Niles Regulating Reservoir. This small storage, with a capacity of five million gallons, was formed by excavation and embankment and is concrete lined. From here, water passes through a three-mile pipeline to Irvington Pumping Station, from which it is pumped into the Hetch Hetchy Aqueduct at Irvington Portal. When water collected at the Sunol Galleries is turbid, it can be pumped to San Antonio Reservoir for eventual treatment at the nearby filtration plant.

In Livermore Valley near Pleasanton an extensive area of deep gravel provides an underground gathering basin from which San Francisco has the right to withdraw and divert fifteen million gallons of water each day. Some one hundred wells have been sunk in these gravels, ranging in depth from 200 to 400 feet, with one carried to 745 feet. During the critical period, 1930-34, about twenty of these wells were

Sunol Water Temple in Alameda County

Old Stone Dam downstream from Pilarcitos Reservoir

operated to produce the allowable draft from a constantly lowering water table. At present there are seventeen usable wells, but water from this source has been supplied only to the town of Sunol and a few local customers within the valley since 1949.

Peninsula Components

Pilarcitos Reservoir

First of the three impounding reservoirs on the San Francisco Peninsula was Pilarcitos, which collects the runoff from the western slope of the mountains between San Francisco Bay and the Pacific Ocean. This lake is eleven miles south of the county line and straddles Pilarcitos Creek, which empties into the ocean at Half Moon Bay. Tributary watershed area is less than half a square mile, but this drainage is on the western slope with elevations reaching 1875 feet; thus, it has the highest average annual rainfall—46 inches—and is the most productive of the Peninsula reservoirs.

The dam is of rolled-fill earth with a puddled clay core, a century old. It was originally constructed to a height of 70 feet in 1867, but eight years later was raised to its present height of 95 feet, with a crest length of 520 feet.

Originally, water from here was delivered by gravity through flumes and pipe directly to Laguna Honda distributing reservoir in San Francisco. The 1906 earthquake made such a mess of the latter pipeline that it was never repaired. Present outlet from the lake is a brick and stone gate tower connecting with a small brick-lined tunnel, which pierces the ridge to the east. Water is conveyed by this tunnel and a pipe to San Andreas Reservoir. Runoff into Pilarcitos is usually in excess of its capacity of one billion gallons so the release to San Andreas permits additional catchment. Water spilled over the dam is picked up at Old Stone Dam about two miles downstream and is diverted by tunnels and concrete pipe to nearby Crystal Springs Reservoir.

San Andreas Reservoir

Lying in a high valley in the hills west of the city of Millbrae is San Andreas Reservoir. This catchment and storage facility is located on a branch of San Mateo Creek two and a half miles north of Pilarcitos. There are about four and a half square miles of watershed on this creek above the dam, but it is supplemented by diversions from Pilarcitos and through short tunnels in the dividing ridge from another branch of San Mateo Creek.

The supply of water in San Andreas is augmented further by pumping from Crystal Springs—capacity of the storage is six billion gallons. The dam here is similar to the one at Pilarcitos, having been initially completed by Spring Valley Water Company in 1870. increased in height in 1875, and again in 1928. It is now 105 feet high with a crest length of 950 feet. It is worthy to note how well this dam withstood the

1906 earthquake. The San Andreas Fault line passes directly through the eastern abutment, but although there was a shearing movement of eight feet along the rift at this point, no damage to the embankment was sustained and the safety of the structure was unimpaired.

There are three outlets from San Andreas. The south outlet supplies water by gravity to Merced Manor Reservoir in San Francisco, and to consumers along the line, through twelve miles of transmission main. The north outlet, added in 1928, sends water through twelve miles of 54-inch main to Sunset, College Hill, and Balboa Reservoirs in the City. A third outlet structure feeds additional water to the other two lines and to the 60-inch transmission main connecting Crystal Springs Reservoir to Sunset Reservoir in San Francisco.

Crystal Springs Reservoir

San Francisco's watershed lands on the Peninsula are now priceless areas of open space in a heavily populated and rapidly growing urban section. The City's most important reservoir in this region of great beauty is Crystal Springs, which has a capacity of 22½ billion gallons of water. In addition to serving as a catchment basin for local runoff, it serves as the terminal reservoir for Hetch Hetchy Aqueduct. San Francisco's determination to preserve the untouched beauty of the area and the purity of its water supply is demonstrated in the City's long and fierce fight regarding location of the State's Junipero Serra Freeway.

The long, narrow Crystal Springs Lake lies about thirteen miles from the City. Dividing the reservoir into two parts is an old earth-fill dam, about three miles from the lower end of the lake. This dam was constructed in 1877 as the original development for the reservoir. With completion of the main concrete dam downstream, the earlier structure was no longer used except to support a roadway across the lake.

The newer Crystal Springs Dam was built in 1888 on San Mateo Creek below the junction of its main branches. It was raised a few feet in 1891 and again in 1911 until it is now 154 feet high, 600 feet long at the crest and 176 feet thick at the base. This is a full gravity type, arched dam, built up of large interlocking blocks of concrete formed and poured in place, and is designed to permit a future increase in height of 45 feet. Here is an excellent example of good concrete construction and the dam appears to be as sturdy today as on the day it was built. The splendid manner in which this structure, located very close to the fault line, survived the 1906 earthquake without the slightest damage, is mute testimony to its excellent design and construction.

There are two outlet towers located near the dam, one built in 1891 and the other 40 years later. Among lines fed by these outlets are two transmission mains, each 17 miles long and mostly of 44- and 60-inch

Crystal Springs Dam with water flowing over the spillway

pipe, which deliver water by gravity to University Mound Reservoir in San Francisco. These lines also serve consumers along the way and distribution facilities of several Peninsula communities as far south as San Carlos. A third main, the 20-mile Sunset Pipeline, 78 and 60 inches in size, delivers Crystal Springs water, after boosting at Lake Merced pumping station, to Sunset Reservoir in the city. The three pipelines are connected, just below Crystal Springs Dam, through a ring manifold from which water can be supplied to any transmission main, or can be pumped to San Andreas Reservoir from either or both outlet towers.

City Distribution Facilities

The water distribution system in San Francisco is one that is extremely complicated because of the many hills. Elevations range from sea level to 900 feet, with abrupt changes in many areas. To provide adequate service to consumers, major pressure zones have been established within the limitations of available sites for reservoirs and tanks. However, on account of the uneven topography of the city, these zones are broken up, particularly in the higher elevations, into a number of isolated areas. There are some 25 different pressure districts formed throughout the city by closed valves between different parts of the pipe system. These districts vary greatly in area and usually can be served from more than one source.

Each of the five transmission mains from the Peninsula reservoirs discharges into one or more of six receiving reservoirs within the City. University Mound and Merced Manor reservoirs are at elevations sufficiently low to receive water by gravity from Hetch Hetchy Aqueduct and from Crystal Springs Reservoir. Merced Manor can receive water by gravity also from San Andreas. Sunset, College Hill, and Balboa reservoirs can be supplied by gravity from San Andreas and by pumping from Crystal Springs. Sutro Reservoir receives water by pumping from either San Andreas or Crystal Springs. Including the six receiving reservoirs, there are a total of twelve distribution reservoirs in service at elevations ranging from 135 to 800 feet. Generally, these storage plants were constructed by excavation and earth embankment and are concrete lined and roofed. Two other reservoirs, the natural Lake Merced and the old Laguna Honda, are maintained solely for emergency supply. If needed, water from Lake Merced can be pumped to higher levels throughout the city. Supplementing the distributing reservoirs there are a number of storage tanks at elevations from 290 to 900 feet with capacities of 75,000 to 300,000 gallons. These tanks serve small, isolated areas where this method of providing service is more economical. Total storage capacity of the reservoirs and tanks within San Francisco is approximately 550 million gallons, equal to about four days' consumption.

The city system includes a number of attended and automatic pumping stations with varying capacities to supply reservoirs and tanks at higher elevations. Hydropneumatic pressure systems are also used for maintaining pressure in small areas having no storage facilities for gravity flow. Water pressures throughout the city are held as far as possible between 40 and 80 pounds per square inch. San Francisco's distribution system comprises over 1150 miles of pipe, not counting transmission mains and hydrant connections, and the sizes vary from five feet in diameter to three-quarters of an inch. The oldest known main in service is a four-inch cast iron pipeline laid in 1859! All water delivered to consumers is metered and the average per capita consumption of water within the City amounts to 120 gallons per day.

Water Purity, Use, and Benefits

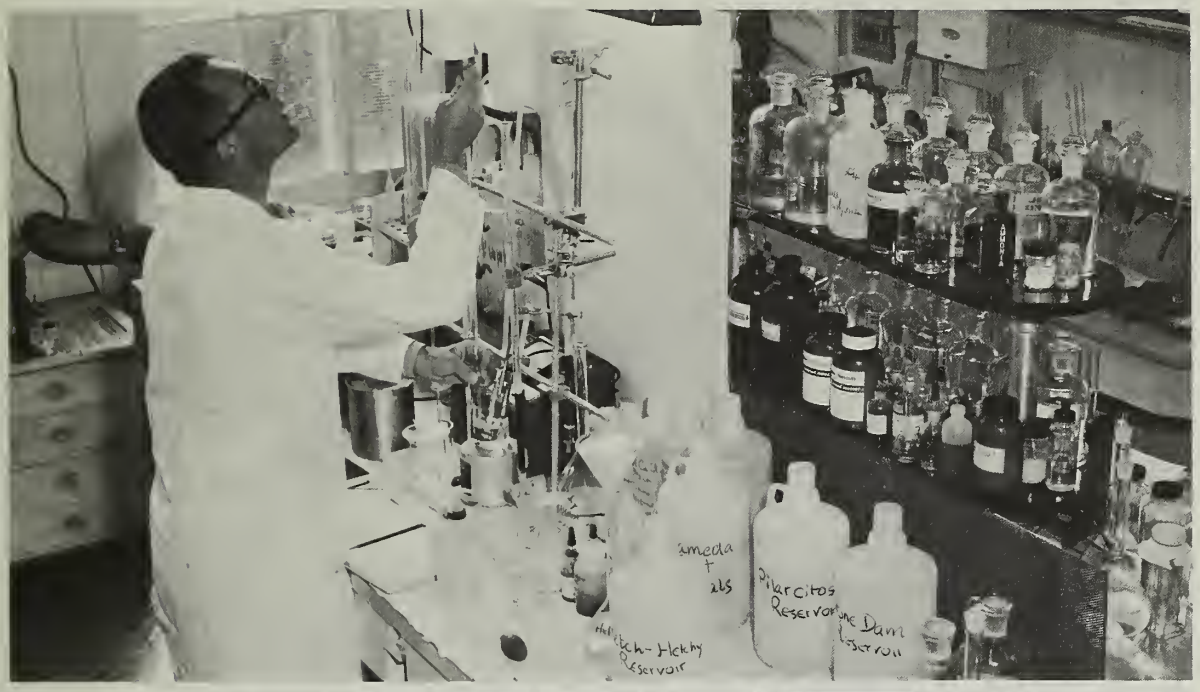
All of San Francisco's water sources are relatively free from pollution. "San Francisco is the last big American city which still delivers into its domestic distribution system water which is pure enough to require no chemical treatment for health reasons," according to a recent national magazine. "Actually there is mild chlorination just for health insurance," the article continues. No waterborne disease has ever been traced to this supply. Hetch Hetchy lies in the higher elevations of the Sierra, where the possibility of contamination is remote. Nevertheless, strict controls are enforced here and at all other watershed areas of the system.

Other controls include a program to keep down the growth of algae on open reservoirs and another whereby quicklime (calcium oxide) is added to the excessively soft Hetch Hetchy water as it passes Rock River in the foothills. This treatment makes the water slightly alkaline and lessens corrosion in the pipelines. As the water flows westward it receives a mild chlorine treatment at Tesla Portal in the Coast Range; safe water is thereby assured and growths in the tunnel are checked. Chlorination takes place at other locations, by means of automatic equipment, wherever the water passes through an open reservoir during transit to the customer. Finally, the entire water supply for the City is fluoridated under a program started after the voters signifed their approval in a 1951 election.

A great deal of effort is expended in keeping the San Francisco water supply clean and clear, even during times of heavy rainfall and ground erosion. Suspended matter in reservoirs is eliminated by artificial clarification, when required. In a more extensive program the first stage of a huge filtration plant was completed in 1966 near Sunol, in Alameda County. This Sunol Valley Water Filtration Plant provides treatment for turbidity (muddiness), color, taste, and odor to the water from all sources in the Alameda County area. The first stage has a design capacity of 40 million gallons per day and the second will bring the capacity to 80 million. Similar filtration plants are planned for treatment of water from the Peninsula reservoirs. The Water Department maintains a well-equipped laboratory which exercises control over the quality and treatment of water, under inspection by the California Department of Public Health.

Recreational use of watershed lands of the Hetch Hetchy Water and Power System in Yosemite National Park and Stanislaus National Forest is under control of Federal agencies. Construction and maintenance of roads and trails by San Francisco in connection with the water and power development has increased accessibility to these remote High Sierra regions for outdoor recreation. New lakes, such as Lake Lloyd on the Cherry, have provided additional fishing waters and areas for boating and camping. Preservation and enhancement of fish and wildlife resources are supported by continuous controlled releases of water from reservoirs into Tuolumne and Cherry Rivers and Eleanor Creek.

San Francisco has made available to the California Department of Fish and Game the use of 34 acres of land in Tuolumne County, immediately below Moccasin Dam, for a fish hatchery. Water up to a maximum of 13 million gallons daily is furnished free by the City for egg-hatching troughs and fish-rearing ponds. Over 2½ million fingerlings, both trout and salmon two to three inches long, and 800,000 catchables (7 to 9 inches) are produced here each year, and these are planted in lakes and streams of the Central Sierra and central coast areas. The Peninsula watersheds are a part of the California Fish and Game Preserve and the area is closed to the public. Similarly, all fishing, boating, and hunting in the Alameda watershed and reservoir property are prohibited. In San Francisco, Lake Merced is maintained solely for emergency water supply. This lake is stocked with trout and is open for fishing and boating under supervision of the San Francisco Recreation and Park Department.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Reservoir

Power Disposal

Legal Obligations The Raker Act expressly prohibits San Francisco from selling Hetch Hetchy electric energy, directly or indirectly, to any private corporation or individual for resale. The intent was to prevent exploitation of the public lands involved for possible private gain. From the time Hetch Hetchy energy was first generated, interpretation of this provision of the Act caused seemingly endless controversy and litigation over a twenty-year period, until it was finally settled in court in 1945. Since the City doesn't possess a municipal electric distribution system, the Raker Act limits disposal of San Francisco's power to its municipal departments, to other public agencies, and to industrial and commercial customers for direct use. The City is specifically required to sell or supply to Modesto and Turlock Irrigation Districts, or to municipalities therein, power, at cost, for pumping and municipal purposes available in excess of San Francisco's own needs. Thereafter, any surplus may be sold for commercial consumption.

Municipal Ownership Efforts Originally, it was planned to bring the Hetch Hetchy power into the City and distribute it through a municipally-owned system, as advocated by City Charter. Much effort was devoted to trying to acquire an electric distribution system, and various approaches were studied: purchase of the privately-owned systems, condemnation of these private utilities under the right of eminent domain, or construction of new, competing facilities. Between 1927 and 1941 a series of bond propositions to finance this acquisition were defeated by the electorate at six different elections. Twice during this period bills were introduced in Congress to amend the Raker Act by eliminating the restrictions on power disposal. In each case the bill died in committee.

In 1925, on completion of Moccasin power plant, a temporary agreement was consummated between the City of San Francisco and the Pacific Gas and Electric Company, intended as an agency contract, for distributing Hetch Hetchy power to consumers in San Francisco. The City would receive payment at an agreed amount per kilowatt-hour. After lengthy investigation, the Secretary of the Interior concluded that the "agency contract" was in violation of the Raker Act. In 1937 suit was filed by the Federal Government and the United States District Court decided that the agreement with Pacific Gas and Electric was actually a contract of sale and was in violation of the Act. This decision was reaffirmed by the United States Supreme Court.

Eventually, after several threats and extensions, San Francisco in 1945 negotiated new contracts for the disposal of Hetch Hetchy power. The contracts, with the irrigation districts and the private utility company, were approved by the Secretary of the Interior, the California Commission, and the Court. In 1960 and 1966 additional agreements were negotiated to provide a legal market for power generated by Dion R. Holm and Robert C. Kirkwood Powerhouses.

Present Market Under present contractual arrangements, Hetch Hetchy energy is sold to the following customers:

1) Municipal departments of the City and County of San Francisco for water supply pumping, San Francisco International Airport, municipal streetcars, cable cars, and trolley buses, street lighting, public buildings, and various other uses. The power is picked up by the Pacific Gas and Electric Company from the City's transmission lines at Newark, handled over their system and delivered to service points. The City pays for these services.
2) Modesto and Turlock Irrigation Districts to supplement generation from their own power plants. Power is delivered directly from the City's transmission lines to the Districts' substations.
3) Certain large industrial firms located in the San Francisco Bay Area whose electric service contracts have been assigned to the City by Pacific Gas and Electric. Power for these customers is supplied to the utility company's system at Newark Substation and Warnerville Substation and is delivered over the company's facilities. The City pays for this service and supplies the transmission losses.

When, at any time, demand of the above customers exceeds the capacity of the Hetch Hetchy system, stand-by service and supplemental power is furnished by Pacific Gas and Electric Company under contractual provisions.

The City's three power plants generate approximately two billion kilowatt-hours of electric energy a year. Gross revenues from the sale of this energy average about $13,000,000 annually.

Conclusion

Something written in 1933 expresses better than anything else the meaning of Hetch Hetchy to the people of San Francisco. In a letter of commendation to San Francisco and her engineers, J. Waldo Smith, Chief Engineer of the Board of Water Supply of New York City, wrote: "When the project is completed, it will stand as one of San Francisco's greatest assets, and as a lasting monument to the energy of the City and its citizens and to their faith in the future."

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